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Arkansas Soybean Research Studies 2019

Jeremy Ross

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Soybean Research Studies 2019

Jeremy Ross, Editor

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Cover photo: Side by side look at the benefit of using a preemergence, residual herbicide (right) compared to no residual (left) for the control of Palmer amaranth in soybean and reducing selection pressure on postemergence herbicides. Photo taken at the Newport Extension Center near Newport, Arkansas. Photo taken by Dr. Thomas (Tommy) R. Butts, Assistant Professor, Extension Weed Scientist, University of Arkansas System Division of Agriculture, Lonoke, Arkansas.

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Arkansas Agricultural Experiment Station (AAES), University of Arkansas System Division of Agriculture, Fayetteville. Mark J. Cochran, Vice President for Agriculture; Jean-François Meullenet, Senior Associate Vice-President for Agriculture–Research and Director, AAES. WWW/CC2020.

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Preface

The 2019 Arkansas Soybean Research Studies includes research reports on topics pertaining to soybean across several disciplines, from breeding to post-harvest processing. Research reports contained in this publication may represent preliminary or only a data set from a single year or limited results; therefore, these results should not be used as a basis for long-term recommendations.

Several research reports in this publication will appear in other University of Arkansas System Division of Agriculture's Arkansas Agricultural Experiment Station publications. This duplication is the result of the overlap in research coverage between disciplines and our effort to inform Arkansas soybean producers of the research being conducted with funds from the Soybean Check-off Program. This publication also contains research funded by industry, federal, and state agencies.

The use of products and trade names in any of the research reports does not constitute a guarantee or warranty of the products named and does not signify that these products are approved to the exclusion of comparable products.

All authors are either current or former faculty, staff, or students of the University of Arkansas System Division of Agriculture, or scientists with the United States Department of Agriculture, Agricultural Research Service.

Extended thanks are given to the staff at the state and county extension offices, as well as the research centers and stations; producers and cooperators; and industry personnel who assisted with the planning and execution of the programs.

Acknowledgments

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Introduction

Arkansas is the leading soybean-producing state in the mid-southern United States. Arkansas ranked 11th in soybean production in 2019 when compared to the other soybean-production states in the U.S. The state represented 3.7% of the total U.S. soybean production and 3.5% of the total acres planted in soybean in 2019. The 2019 state soybean average yield was 49.0 bushels per acre, two bushels lower than the state record set in 2017. The top five soybean-producing counties in 2019 were Mississippi, Arkansas, Crittenden, Poinsett, and Desha Counties (Table 1). These five counties accounted for 35.5% of soybean production in Arkansas in 2019.

The 2019 growing season was a struggle for many soybean producers, not only in Arkansas but in much of the soybean-producing region of the U.S. Excessive rainfall starting in the fall of 2018 and continuing through the spring months of 2019 hampered preplant tillage activities and delayed planting for many Arkansas soybean producers. Historical flooding was seen along the Arkansas River, which impacted many producers in the Arkansas River Valley. Additional flooding was seen along the Mississippi, White, and Cache Rivers and other tributaries. Due to these wet soil conditions, soybean planting was delayed. According to the 3 June 2020 USDA-NASS Arkansas Crop Progress and Condition Report (USDA-NASS, 2019), only 54% of the soybean acreage had been planted as of the first of June compared to the 5-year average of 79%. This delay in planting also reduced the planted soybean acreage to 2.65 million acres, the lowest soybean acreage planted in the state since 1961. In addition to poor soil conditions, many producers had to replant soybean fields due to poor seed quality. The poor-quality seed was due to the adverse weather conditions seen at harvest during the fall of 2018. Soybean seed samples tested by the Arkansas State Plant Board showed the average germination and accelerated aging of 77% and 57%, respectively. This was a large decline when compared to the 2018 results for the average germination of 91% and accelerated aging of 84%. Additionally, soybean producers across the U.S. experienced low commodity prices for soybean due to the reduction in trade to China.

Overall, disease and insect issues were not a problem in 2019. Most soybean-producing counties in Arkansas have some level of Palmer amaranth that has multiple herbicide resistance, and soybean production in these fields is becoming very difficult due to the loss of many herbicides. The 2019 growing season was the third year where the use of dicamba was labeled for over-the-top applications on dicamba-tolerant soybean. Soybean producers in Arkansas were restricted from applications of dicamba from 16 April to 31 October. Even with these restrictions on applications, complaints were filed with the Arkansas State Plant Board for non-dicamba soybean fields showing dicamba symptomology.

Table 1. Arkansas soybean acreage, yield, and production by County, 2018-2019[a]

	Acres Planted		Acres Harvested		Yield		Production	
County	**2018**	**2019**	**2018**	**2019**	**2018**	**2019**	**2018**	**2019**
	-----------acres-----------		-----------acres-----------		-----bu./ac-----		---------------bu.---------------	
Arkansas	171,800	160,500	170,900	159,600	59.8	58	10,218,000	9,254,000
Ashley	57,500	39,400	56,600	38,900	54.9	50.6	3,107,700	1,970,000
Chicot	166,000	145,000	165,500	143,200	52	54.1	8,614,000	7,750,000
Clay	109,900	89,000	108,800	88,500	50.8	48	5,528,000	4,250,000
Conway	17,600	*	17,250	*	37	*	639,000	*
Craighead	96,900	74,100	95,700	73,600	50	46.3	4,784,000	3,404,000
Crittenden	*	179,000	*	176,400	*	46.1	*	8,130,000
Cross	151,500	135,000	148,600	132,900	53.3	52	7,913,000	6,915,000
Desha	181,700	135,500	181,500	133,700	59.5	59.8	10,798,000	8,000,000
Drew	39,400	27,800	39,100	27,500	56.9	57.5	2,225,800	1,580,000
Faulkner	7,600	*	7,450	*	43.2	*	322,000	*
Greene	73,700	52,800	70,800	52,300	41.5	45.8	2,940,000	2,396,000
Independence	*	25,600	*	25,400	*	40.9	*	1,038,000
Jackson	121,500	102,000	120,000	101,100	40.1	40.3	4,812,000	4,070,000
Jefferson	110,000	73,900	106,600	70,600	56.5	54.3	6,027,000	3,835,000
Lawrence	62,100	46,800	61,400	46,700	40.4	39.9	2,478,000	1,864,000
Lee	139,400	*	136,400	*	44.4	*	6,057,000	*
Lincoln	70,400	55,400	69,900	55,100	55.4	57.2	3,869,500	3,150,000
Little River	*	9,100	*	9,100	*	30.2	*	275,000
Lonoke	*	94,200	*	93,400	*	48.2	*	4,500,000
Mississippi	269,600	235,000	268,400	233,500	50.5	47.6	13,567,000	11,126,000
Monroe	98,300	73,000	97,100	72,000	47.3	47.7	4,593,500	3,435,000
Phillips	207,000	*	205,200	*	50.5	*	10,371,000	*
Poinsett	178,700	159,000	176,100	157,500	56.4	51	9,940,000	8,029,000
Prairie	103,000	102,000	102,000	101,600	53.6	44	5,469,500	4,470,000
Pulaski	22,300	*	21,150	*	44.3	*	937,000	*
Randolph	*	27,000	*	26,400	*	42.5	*	1,123,000
St. Francis	150,400	133,000	147,800	132,200	46.2	50.3	6,823,000	6,650,000
White	*	25,700	*	25,000	*	43	*	1,075,000
Woodruff	129,100	105,000	125,800	103,500	45.8	43.8	5,766,000	4,536,000
Other Counties	426,900	275,900	421,600	267,500	41.8	40.8	20,789,500	12,732,000
State Totals	3,270,000	2,650,000	3,210,000	2,610,000	50.5	49	162,105,000	127,890,000

[a]Data obtained from USDA-NASS, 2020.

*Included in "Other Counties"

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2019 Soybean Research Verification Program

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Abstract

The 2019 Soybean Research Verification Program (SRVP) was conducted on 20 commercial soybean fields across the state. Counties participating in the program included; Arkansas, Ashley, Chicot, Clark, Cross, Desha, Greene, Jackson (2), Jefferson, Lawrence, Lee, Lonoke, Miller, Mississippi, Monroe, Phillips, Poinsett, White, and Woodruff Counties for a total of 1,166 acres. Grain yield in the 2019 SRVP averaged 55.2 bu./ac ranging from 23.9 to 75.0 bu./ac. The 2019 SRVP average yield was 5.2 bu./ac greater than the estimated Arkansas state average of 50 bu./ac. The highest yielding field was in Lee County with a grain yield of 75.0 bu./ac. The lowest yielding was in Phillips County and produced 23.9 bu./ac.

Introduction

In 1983, the University of Arkansas System Division of Agriculture's Cooperative Extension Service (CES) established an interdisciplinary soybean educational program that stresses management intensity and integrated pest management to maximize returns. The purpose of the Soybean Research Verification Program (SRVP) is to verify the profitability of CES recommendations in fields with less than optimum yields or returns. The goals of the SRVP are to 1) educate producers on the benefits of utilizing CES recommendations to improve yields and/or net returns, 2) conduct on-farm field trials to verify research-based recommendations, 3) aid researchers in identifying areas of production that require further study, 4) improve or refine existing recommendations which contribute to more profitable production, and 5) incorporate data from SRVP into CES educational programs at the county and state level. Since 1983, the SRVP has been conducted on 642 commercial soybean fields in 33 soybean-producing counties in Arkansas. The program has typically averaged about 10 bu./ac better than the state average yield. This increase in yield over the state average can mainly be attributed to intensive cultural management and integrated pest management.

Procedures

The SRVP fields and cooperators are selected prior to the beginning of the growing season. Cooperators agree to pay production expenses, provide expense data, and implement CES production recommendations in a timely manner from planting to harvest. A designated county agent from each county assists the SRVP coordinator in collecting data, scouting the field, and maintaining regular contact with the producer. Weekly visits by the coordinator and county agents were made to monitor the growth and development of the crop, determine what cultural practices needed to be implemented and to monitor type and level of weed, disease and insect infestation for possible pesticide applications.

An advisory committee consisting of CES specialists and university researchers with soybean responsibility assists in decision-making, development of recommendations, and program direction. Field inspections by committee members were utilized to assist in fine-tuning recommendations.

In 2019 the following counties participated in the program; Arkansas, Ashley, Chicot, Clark, Cross, Desha, Greene, Jackson (2), Jefferson, Lawrence, Lee, Lonoke, Miller, Mississippi, Monroe, Phillips, Poinsett, White, and Woodruff counties. The 20 soybean fields totaled 1166 acres enrolled in the program. Three Roundup Ready® varieties (Pioneer P47T36R, Terral REV 48A26, and UA 5414RR), 5 Roundup Ready 2 Xtend® varieties (Armor 46-D08, Armor 48-D24, Asgrow AG46X6, Pioneer P42A43X, and Pioneer P48A32X), 9 LibertyLink® varieties (Bayer CZ 4918LL, Merschman Miami 1949 LL, Pioneer P45A29L, Pioneer P47A76L, Progeny 5414LLS, Stine 49LD02, Stine 49LH02, Stine 51LI32 and Terral REV 47L38) and 1 conventional variety (NSGA DrewSoy 5.0) were planted, and CES recommendations were

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used to manage the SRVP fields (Table 1). Agronomic and pest management decisions were based on field history, soil test results, variety, and data collected from individual fields during the growing season. An integrated pest-management philosophy is utilized based on CES recommendations. Data collected included components such as stand density, weed populations, disease infestation levels, insect populations, rainfall, irrigation amounts, and dates for specific growth stages (Tables 1 and 2).

Results and Discussion

Yield. The average SRVP yield was 55.2 bu./ac with a range of 23.9–75.0 bu./ac (Table 2). The SRVP average yield was 5.2 bu./ac more than the estimated state yield of 50 bu./ac. This difference has been observed many times since the program began and can be attributed in part to intensive management practices and utilization of CES recommendations. The highest yielding field yielded 75.0 bu./ac and was seeded with Pioneer P47T36R in Lee County.

Planting and Emergence. Planting began with Desha County on 27 April and ending with Clark County planted 20 June. An average of 149,000 seeds/ac was used for planting across all locations. An average of eight days was required for emergence. Please refer to Table 2 for agronomic information for each location.

Fertilization. Fields enrolled in the SRVP were fertilized according to the University of Arkansas System Division of Agriculture's Soil Test Laboratory results and current soybean fertilization recommendations. Refer to Table 3 for detailed fertility information.

Weed Control. Fields were scouted on a weekly basis, and CES recommendations were utilized for weed control programs. Refer to Table 4 for herbicide rates and timings.

Disease/Insect Control. Fields were scouted on a weekly basis, and CES recommendations were utilized for disease and insect control programs. Refer to Table 5 for fungicide and insecticide applications.

Irrigation. All fields receiving supplemental irrigation were enrolled in the University of Arkansas System Division of Agriculture's Irrigation Scheduler Computer Program and utilized computerized hole selection programs such as PHAUCET or PipePlanner. Irrigation events were recommended based on information generated from these programs. Sixteen of the 20 fields in the 2019 SRVP were furrow irrigated, 2 were pivot irrigated, and 2 were dry land.

Practical Applications

Data collected from the 2019 SRVP reflected slightly higher soybean yields, as was the state average, and maintained above-average returns in the 2019 growing season (data not shown). Analysis of this data showed that the average yield was higher in the SRVP compared to the state average, and the cost of production was equal to or less than the Cooperative Extension Service-estimated soybean production costs (Watkins, 2019).

Acknowledgments

We appreciate the cooperation of all participating soybean producers and thank all Arkansas soybean growers for financial support through the soybean check-off funds administered by the Arkansas Soybean Research and Promotion Board. We appreciate the cooperation of all participating County Extension Agents. We also thank the professors, specialists, and program associates of the University of Arkansas System Division of Agriculture's Agricultural Experiment Station and Cooperative Extension Service along with the district administration for their support.

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Table 1. Agronomic information for the 2019 Soybean Research Verification Fields.

County	Variety	Field size	Previous crop[a]	Production system[b]	Seeding rate	Stand density
		ac			seeds/ac	plants/ac
Arkansas	Pioneer P45A29L	28	Rice	FSI	130K	82K
Ashley	Terral REV 48A26	51	Corn	FSI	140K	124K
Chicot	Armor 46D08	55	Rice	LSI	146K	85K
Clark	Pioneer P48A32X	60	Corn	LSI	140K	95K
Cross	Armor 48D24	90	Soybean	FSI	160K	139K
Desha	Armor 48D24	80	Soybean	FSI	140K	83K
Greene	Stine 49LD02	35	Rice	LSI	140K	90K
Jackson 1	UA 5414RR	45	Soybean	LSI	2.05 bu.	176K
Jackson 2	Pioneer P47A76L	46	Corn	FSI	140K	114K
Jefferson	Pioneer P42A43X	46	Corn	FSI	140K	120K
Lawrence	Asgrow AG46X6	30	Corn	FSI	133K	112K
Lee	Pioneer P47T36R	39	Corn	FSI	135K	120K
Lonoke	Bayer CZ 4918 LL	40	Corn	LSI	137K	115K
Miller	Merschman Miami 1949 LL	76	Soybean	FSNI	140K	120K
Mississippi	Asgrow AG46X6	65	Rice	LSI	140K	115K
Monroe	Progeny 5414 LLS	40	Corn	LSI	155K	100K
Phillips	Stine 49LH02	30	Soybean	LSNI	140K	80K
Poinsett	NSGA DrewSoy 5.0	132	Rice	LSI	150K	122K
White	Terral REV 47L38	28	Soybean	LSI	140K	109K
Woodruff	Stine 51LI32	150	Rice	LSI	175K	144K
Average		**58**			**149K**	**112K**

[a] Rice = *Oryza sativa*; Corn = *Zea mays*; Soybean = *Glycine max.*

[b] Production Systems: FSI = Full-season Irrigated; FSNI = Full-season Non-irrigated; LSI = Late-season Irrigated.

Table 2. Planting, emergence, and harvest dates and adjusted soybean grain yield for the fields in the Soybean Research Verification Program, 2019.

County	Planting date	Emergence date	Harvest date	Yield adj. to 13% moisture[a]
				bu./ac
Arkansas	5/1	5/8	10/1	74.6
Ashley	5/8	5/17	9/17	67.9
Chicot	6/12	6/19	11/3	41.0
Clark	6/20	6/26	10/18	40.1
Cross	5/18	5/25	10/3	59.6
Desha	4/27	5/6	9/28	66.1
Greene	6/14	6/20	10/25	59.1
Jackson 1	6/4	6/15	10/23	37.0
Jackson 2	5/24	5/31	10/24	64.3
Jefferson	5/27	6/3	9/26	70.3
Lawrence	4/28	5/3	10/5	54.2
Lee	5/17	5/24	10/3	75.0
Lonoke	6/2	6/9	10/3	67.8
Miller	5/25	6/1	10/20	25.7
Mississippi	6/2	6/11	11/15	70.7
Monroe	6/2	6/10	10/29	56.0
Phillips	6/1	6/9	10/7	23.9
Poinsett	6/13	6/19	10/18	51.5
White	6/4	6/12	10/13	48.4
Woodruff	6/18	6/26	11/5	50.4
Average	**5/27**	**6/4**	**10/14**	**55.2**

[a] 2019 Arkansas state soybean average yield was 50.0 bu./ac.

Table 3. Soil test results, applied fertilizer and soil classification for the 2019 Soybean Research Verification Fields

County	Soil Test Results pH	P	K	Applied Fertilizer N-P-K Pre-plant	Soil Classification
	---------------	ppm	--------------	lb/ac	
Arkansas	6.2	30	112	0-0-60	Hebert, Rilla silt loam, Portland clay
Ashley	7.2	28	54	0-50-70	Calhoun, Calloway silt loam
Chicot	6.7	38	144	0-0-60	Perry clay
Clark	6.4	30	133	0-0-50	Tuscumbia silty clay, Marietta fine sandy loam
Cross	6.5	22	252	0-50-0	Alligator and Earle clay
Desha	7.4	37	337	0-0-0	Sharkey and Desha clays
Greene	6.6	12	86	0-60-120	Jackport silty clay loam
Jackson 1	6.3	13	112	0-0-0	Egam silt loam
Jackson 2	6.6	78	156	1 ton poultry litter	Egam silt loam
Jefferson	7.1	45	78	0-0-120	Perry clay, Coushatta silt loam
Lawrence	6.5	25	85	0-50-120	Bosket fine sandy loam
Lee	7.8	45	134	0-54-108	Calloway, Hillemann silt loam
Lonoke	6.2	26	82	0-50-120	Calloway, Calhoun silt loam
Miller	6.1	31	197	0-0-0	Bossier clay
Mississippi	7.5	28	330	0-0-0	Sharkey-Steele complex
Monroe	7.3	16	121	0-100-80	Foley-Calhoun-Bonn Complex
Phillips	5.4	26	94	0-0-75	Loring, Grenada silt loam
Poinsett	7.1	11	59	0-60-160-.5B	Henry, Hillemann silt loam
White	6.1	16	62	0-60-120	Calhoun silt loam
Woodruff	6.7	5	151	0-80-50	Jackport silty clay loam

Table 4. Herbicide rates and timings for 2019 Soybean Research Verification Program fields by county.

County	Herbicide: Burndown/Pre-emergence	Herbicide: Post-emergence
Arkansas	Pre-emerge; 1.5 pt Boundary®	1st; 1 qt Liberty® + 2 oz Zidua 2nd; 1 qt Liberty + 1.5 pt Me-Too-Lachlor
Ashley	Pre-emerge; 1 pt Charger Basic®	1st; 1 qt Cornerstone 2nd; 1 qt Cornerstone + 1 qt Prefix + 6 oz Flexstar
Chicot	Pre-emerge; 22 oz RoundUp® PowerMax™ + 5 oz Verdict®	1 qt Cornerstone + 1 pt Dual Magnum Harvest aid; 1 pt Gramoxone + 1% NIS
Clark	Pre-emerge; 1 qt. Cornerstone® + 1.5 pt Me-Too-Lachlor	1st; 1 pt Ultra Blazer® + 1 qt Cornerstone 2nd; 24 oz Envy 6 Max + 2 oz Zidua 3rd; 1 pt Ultra Blazer + 1 qt Cornerstone
Cross	Burndown; 40 oz paraquat Pre-emerge; 1.75 pt Boundary	1st; 1 qt glyphosate + 1 qt Prefix + 6 oz Flexstar® 2nd; 1 qt glyphosate
Desha	Pre-emerge; 1 qt Cornerstone® + 5 oz Verdict	1st; 22 oz RoundUp PowerMax + 1.3 pt Dual Magnum 2nd; 1 qt Cornerstone + 1 qt Prefix
Greene	Pre-emerge; 1.25 pt S-metolachlor	1st; 1 qt Liberty + 1.25 pt S-metolachlor 2nd; 1 qt Liberty
Jackson 1	Burndown; 32 oz RoundUp PowerMax + 1 oz Sharpen® Pre-emerge: 1 qt metolachlor	1st; 22 oz RoundUp PowerMax + 1 pt Flexstar
Jackson 2	Pre-emerge; 1 qt Paraquat + 1 qt Moccasin® MTZ	1st; 1 qt Liberty 2nd; 1 qt Liberty + 1 pt S-metolachlor 3rd; 1 pt Flexstar
Jefferson	Pre-emerge; 1 qt Boundary	36 oz Prefix + 1 qt Cornerstone
Lawrence	Pre-emerge; 2 oz Valor® + 1 pt Prowl® + 0.3 lb Metribuzin	1st; 1 qt Cornerstone + 1 qt Prefix 2nd; 1 qt Cornerstone
Lee	Pre-emerge; 1.3 pt Boundary	1 qt RoundUp PowerMax + 1 qt Prefix + 10 oz Section III
Lonoke	Pre-emerge; 1 qt Prefix®	1st; 1 qt Interline® 2nd; 1 pt Ultra Blazer + 0.25% NIS + 2 oz Zidua
Miller	Burndown; 1 pt 2,4-D + 2 oz Valor Pre-emerge; 1.3 pt Dual Magnum®	1st; 1 qt Interline + 8 oz Section III + 3 lb AMS 2nd; 1.5 pt Flexstar + 8 oz Section III
Mississippi	Pre-emerge; 22 oz Galavant +1 oz valor + 48 oz Gramoxone®	1st; 1 qt RoundUp PowerMax + 48 oz Warrant Ultra
Monroe	Pre-emerge; 1 qt Cornerstone + 1 oz Sharpen	1st; 1 qt Liberty + 1 pt Dual Magnum + 8 oz Select Max 2nd; 1 qt Liberty + 8 oz Select Max
Phillips	Pre-emerge; 1 pt Dual Magnum	1st; 1 qt Liberty 2nd; 1 qt Liberty + 1.2 pt Dual Magnum
Poinsett	Pre-emerge; 1 qt Boundary; 1 oz Zidua®	1st; 8 oz Intensity + 1 pt S-metolachlor
White	Pre-emerge; 1 qt Headwin	1st; 32 oz Interline + 16 oz Me to Lachlor
Woodruff	Pre-emerge; 3 pt Warrant®	1st; 40 oz Cheetah® 2nd 40 oz Cheetah + 8 oz Clethodim 2E

Table 5. Fungicide and insecticides applications in 2019 Soybean Research Verification fields by county.

County	Aerial Web Blight	Frogeye	Bollworm/Defoliators	Stink Bug
Arkansas	--------	--------	--------	--------
Ashley	--------	--------	--------	5.12 oz Tundra® + 1% COC
Chicot	--------	--------	1.3 oz Heligen® + 1% COC	5.12 oz Brigade® + 1% NIS
Clark	--------	--------	1.5 oz Heligen + 1% COC	--------
Cross	--------	--------	--------	--------
Desha	--------	--------	--------	--------
Green	--------	--------	--------	--------
Jackson 1	--------	--------	14 oz Prevathon®	--------
Jackson 2	--------	--------	--------	--------
Jefferson	--------	13.7 oz Miravis® Top	--------	--------
Lawrence	--------	--------	--------	--------
Lee	--------	--------	--------	--------
Lonoke	--------	--------	--------	5.12 oz Tundra + 1% COC
Miller	--------	--------	--------	6.4 oz Brigade + 0.5 lb acephate
Mississippi	--------	--------	--------	--------
Monroe	--------	--------	1.28 oz Heligen + 1 % COC	--------
Phillips	--------	--------	10 oz Besiege®	5 oz Brigade
Poinsett	--------	--------	1.28 oz Heligen + 1% COC	--------
White	--------	--------	--------	--------
Woodruff	--------	--------	1.28 oz Heligen	--------

Developing a New Staging System for Soybean

C. Santos,[1] L.C. Purcell,[1] and W.J. Ross[2]

Abstract

An accurate and descriptive staging system for soybean growth and development is important for identifying management decisions throughout the cropping cycle. The currently used staging system dates back more than 47 years and has limitations, especially during seed growth, that do not fully describe the overlapping periods of flowering, pod setting, and seed fill. The current research evaluated a set of 16 cultivars ranging from maturity group (MG) 0 to 7. All cultivars were staged twice a week using the familiar 'V' and 'R' designations along with a new system that identified overlapping periods of flowering, pod setting, and seed filling. Yield ranged from 49 to 71 bu./ac among cultivars, but with the exception of MG 0, all MGs had at least one cultivar that was not significantly different from the highest-yielding cultivar. The new staging system was successful in illustrating the overlap among flowering, pod setting, and seed filling.

Introduction

An accurate soybean [*Glycine max* (L.) Merr.] staging system is critical to the soybean industry. A staging system provides a common language for producers, agricultural scientists, and crop consultants to communicate when planning scouting timelines, irrigation requirements, pesticide applications, anticipated harvest dates, and other management considerations. The most commonly used staging system was originally proposed in 1971 (Fehr et al., 1971) and was slightly modified in 1977 (Fehr and Caviness, 1977). This system uses the familiar 'V' stages for vegetative growth and the 'R' stages for reproductive growth. Although the V stages are fairly intuitive, they have been described differently in publications describing the Fehr and Caviness (1977) system. For example, Pedersen (2004) defined V stages based upon the number of trifoliolate leaves rather than main-stem nodes, as was done originally.

The description of the R stages begins with flowering (R1) and progresses to R8 at harvest maturity, but the determination of the R stages is somewhat subjective and confusing. For instance, R3 is defined when a pod at one of the four uppermost nodes is 3/16 of an inch in length, and R4 is defined when a pod at one of the four uppermost nodes is 3/4 of an inch in length (Fehr and Caviness, 1977). However, new nodes of indeterminate cultivars continue to be added until seed fill (R5), resulting in a staging system that may move back and forth between R3 and R4 several times. Additionally, a primary limitation of the Fehr and Caviness (1977) system is the description of the seed-filling period (R5 to R7) that does not accurately reflect the beginning or end of this critical period of crop development.

The objectives of this study were, first, to develop a consistent and simple system for describing soybean phenology for determinate and indeterminate cultivars during both vegetative and reproductive stages. The second objective was to determine how specific growth stages may overlap with each other in cultivars of different maturity.

Procedures

In collaboration with scientists at Virginia, Mississippi, Minnesota, Wisconsin, and Ohio, the study was performed using 16 Asgrow cultivars that spanned maturity groups (MGs) from 0 to 7. In Arkansas, the study was conducted at the University of Arkansas System Division of Agriculture's Milo J. Shult Agricultural Research and Extension Center, Fayetteville. The experiment was planted 6 June 2017 in plots that consisted of 4 rows, 18 in. apart, and that were 20-ft in length. The seeding density was 150,000 per acre. The experiment was a two-factor split-plot arrangement of treatments in a randomized complete block design with three replications. The whole plot factor was maturity, with cultivars being grouped with a similar relative maturity (over no more than two full MGs) and cultivar being the subplot factor. The experiment was sprinkle-irrigated at a 1.5-in. deficit.

Phenology data were collected twice a week using the system devised by Fehr and Caviness (1977). We also used a

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system similar to Fehr and Caviness (1977) that shows when, for example, plants have the first and last R5 pods anywhere on the plant (not just the top-most four nodes). Similar distinctions were made for the other growth stages, resulting in several stages that overlapped.

At maturity, the two central rows of each plot were harvested. The grain was weighed, and yield was corrected to 13% moisture.

Results and Discussion

Grain yield ranged from 49 to 71 bu./ac (Fig.1), but with the exception of MG 0, all MGs had at least one cultivar with yields that did not differ from the highest yielding cultivar, AG7535. Short-season cultivars (MGs 2 and 3) often have similar yields to full-season cultivars but require substantially less irrigation (Edwards and Purcell, 2005), and results from the present research support that conclusion. For MGs 0, 1, 2, and 3, there were three irrigations between emergence and R6.5 totaling 3.8 inches. For MGs 4 and 5, there were four irrigations between emergence and R6.5 totaling 5.3 inches, and for MGs 6 and 7, six irrigations were totaling 8.3 inches.

In Figure 2, the total duration of the cropping cycle from emergence to harvest maturity (R8) ranged from 80 days (MG 0) to 128 days (MG 7). The day after emergence at which cultivars from the various MGs reached specific growth stages as defined by Fehr and Caviness are shown as solid symbols. The horizontal colored bars show the overlap among growth stages. For example, MG 4 cultivars, began flowering about 25 days after emergence (R1) and continued to flower till 62 days after emergence. This flowering period overlapped with the period on which R3 pods were on the plant (35-65 days), R4 pods were on the plant (42-70 days), and when R5 pods were on the plant (55-78 days).

Practical Applications

This new staging system may have advantages over Fehr and Caviness (1977) in making management decisions and in understanding how environmental conditions or management practices may impact developing pods and flowers and the duration of seed filling.

Acknowledgments

The authors gratefully acknowledge partial funding of this research from the Arkansas Soybean Promotion Board. Support was also provided by the University of Arkansas System Division of Agriculture.

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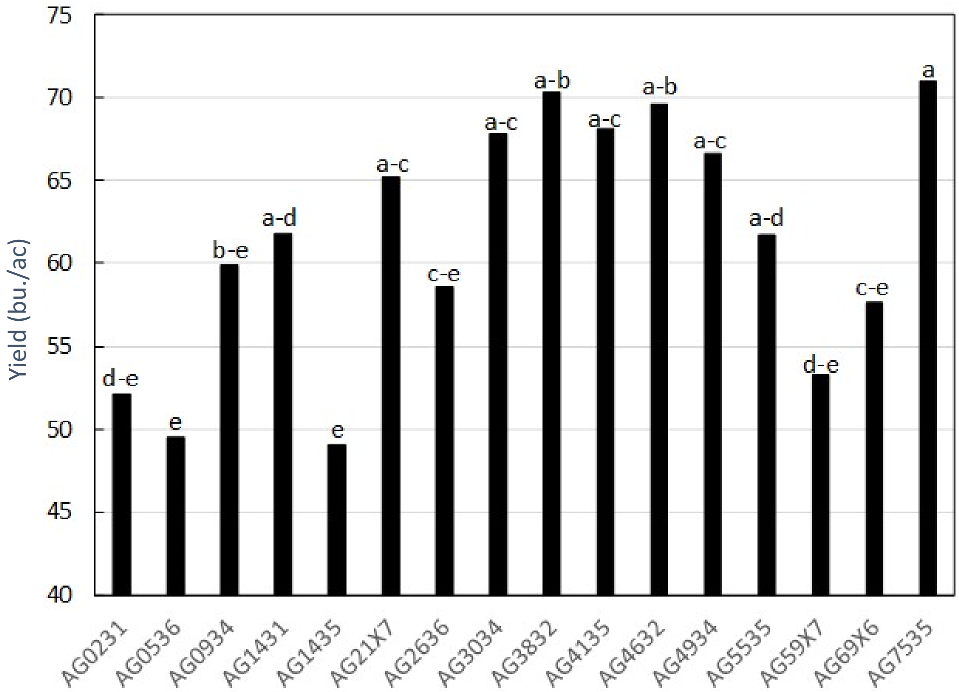

Fig. 1. The yield of soybean cultivars differing in maturity; genotypes are arranged with earliest-maturing genotypes on the left and later-maturing genotypes moving progressively to the right. Different letters above bars indicate significant differences ($P \leq 0.05$) as determined by a least significant difference test.

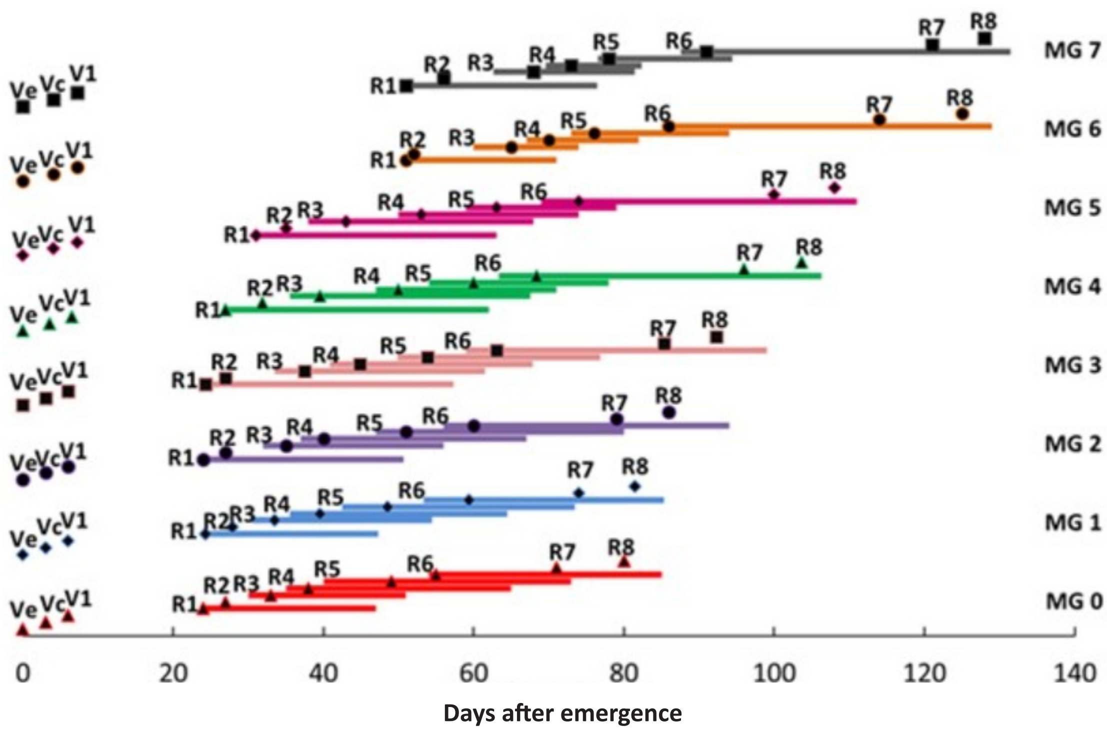

Fig. 2. Phenological stages of development versus days after emergence for maturity group (MG) 0 through 7 cultivars. The symbols in the figure represent the date at which various stages of development were reached according to the Fehr and Caviness (1977) system including emergence (Ve), cotyledonary (Vc), first true leaf (V1), beginning flowering (R1), full flower (R2), beginning pods (R3), early pods (R4), full pods (R5), full seed (R6), physiological maturity (R7), and harvest maturity (R8). The length of the horizontal bars represents the duration that reproductive structures (flowers, pods, seeds) as defined by Fehr and Caviness (1977) remained on the plant, regardless of nodal position.

Economic Feasibility of Inoculating Soybean Seed or Fertilizing Soybean with Nitrogen at Different Planting Dates

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Abstract

Inoculating soybean [*Glycine max* (L.) Merr] with *Bradyrhizobium japonicum* and/or applying nitrogen (N) fertilizer has had mixed results in terms of generating a positive yield response. To evaluate whether or not it is profitable to either inoculate seed, fertilize with nitrogen, or both, and to determine the impact these practices may have at different planting dates, maturity group (MG) 4 and MG 5 cultivars were planted late May or early June vs. late June from 2017 to 2019 at both the University of Arkansas System Division of Agriculture's Milo J. Shult Agricultural Research and Extension Center in Fayetteville, and the Pine Tree Research Station near Colt, Ark. On a per-acre basis, inoculated soybean received either 0 or 50 pounds of N fertilizer whereas uninoculated treatments were fertilized at rates of 0, 25, 50, 100, or 150 pounds of N at R2. While a positive yield response to N-fertilizer was observed and more so for early planted soybean regardless of location or MG, the yield response was small and only marginally significant. At the same time, the impact of inoculation resulted in a small (approximately 1 bu./ac) negative impact on yield that was statistically significant. Economically, the positive yield responses to fertilizer observed were so small that only minimal levels of N fertilizer were justified, and only so if application costs were ignored. At best, should fertilizer application cost be ignored, assuming $15/bu. soybean with $360/ton for urea, the estimated profit-maximizing N fertilizer application rate was 8.4 lb/ac, which translated to a 0.6 bu./ac increase or $5.43/ac extra profit compared to not applying fertilizer when soybean was planted early.

Introduction

Most research has found little or no benefit to the inoculation of soybean seed with *Bradyrhizobium japonicum* in fields where soybean has been grown previously, although the strain of inoculant may make a difference (Hasan, Rahman, and Islam, 2007). However, Roberts et al. (2015) reported a yield increase when soybean was planted mid-June or later with no significant response to inoculant for May planting dates at either the University of Arkansas System Division of Agriculture's Pine Tree Research Station or the Rohwer Research Station. Further, yield increases associated with inoculation were substantial and ranged between 8 and 13 bu./ac for June and July planting dates.

Based upon the positive yield response of late-planted soybean to inoculation, the question arises if yield would also respond favorably to nitrogen (N) fertilization in late-planted soybean. There is considerable interest among soybean producers about N fertilization fueled in part by yield contest winners, many of whom have applied N fertilizer or manures to their contest fields. An extensive scientific review published in 2008 (Salvagiotti et al., 2008) concluded that under optimum growing conditions (primarily without nutrient or soil-moisture limitations), nitrogen fixation could support yields of up to 80 to 85 bu./ac; yields greater than this would require N fertilizer or the availability of mineralized soil N. Evidence in the literature about yield increases associated with N fertilizer is somewhat scant. Beard and Hoover (1971) showed no statistically significant differences in yield. Wesley et al. (1998) reported an average increase in yield of 12% in Kansas under irrigated conditions in 6 of 8 fields. Al-Ithawi et al. (1980) had similar yield improvement under no moisture stress in Nebraska in 1 of 2 years with N application as high as 100 lb/ac. There is little or no information about the amount of N fertilizer that would expectantly give a yield response and if the anticipated yield response was economically justified.

The United States Department of Agriculture National Agricultural Statistics Service (USDA-NASS) and USDA Economic Research Service (ERS) data on N fertilization rate and adoption of this practice in Arkansas are shown in Fig. 1 panels A and B, respectively (USDA-ERS, 2020a).

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While N fertilizer rate shows an upward trend that has likely leveled off around 35 lb/ac, the adoption rate of this practice may be on the decline or at most level. Fig. 1, panels C and D show rate of use and adoption rate, respectively, when plotted against the same year's prevailing ratio of the soybean price index to the N fertilizer cost index (USBLS, 2020; USDA ERS, 2020a). A higher ratio supports greater use of N fertilizer from a profitability perspective as the value of the crop, relative to the cost of the fertilizer is higher. That is for each pound of N fertilizer applied, the revenue created would be higher than the cost increase in a year with a high revenue/cost ratio, assuming other conditions remain constant. The trend line in Fig. 1C suggests that producers are behaving rationally, whereas the trend line in Fig. 1D does not. Panel E shows an upward state-wide irrigated soybean yield trend (USDA-NASS, 2020b).

The objective of this research was to assess soybean yield response to N fertilizer and inoculant when planted early or late and at two locations. With the positive soybean yield effect of N fertilizer expected to diminish at higher fertilizer application rates, we also estimate the profit-maximizing N fertilizer rate. That profit-maximizing application rate occurs where the constant cost per added lb/acre of N-fertilizer meets with the declining rate of added revenue per pound of N-fertilizer/ac.

Procedures

Experimental Data. A MG 4 cultivar (P47T36) and MG 5 cultivar (UA5715GT) were planted at the University of Arkansas System Division of Agriculture's Milo J. Shult Research and Extension Center in Fayetteville and the Pine Tree Research Station in Pine Tree, Ark. at a seeding rate of 125,000/ac as shown in Table 1. Plots consisted of four rows, 20-ft in length, spaced 18 in. apart at Fayetteville and 15 in. apart at Pine Tree. Approximately 2 weeks prior to planting, a portion of the seed was inoculated with Optimize® 400. When plants reached R2, plots receiving the uninoculated seed were fertilized with either 25, 50, 100, and 150 lb N/ac with Agrotain® treated urea. Plots with inoculated seed received either no N fertilizer or 50 lb N/ac. In addition to these treatments, we included a non-nodulating genotype that received no N fertilizer. All treatment combinations for each planting date were replicated four times in a randomized complete block design and repeated in 2018 and 2019. Table 1 summarizes minor changes to experimental design across year and location. Within a week of emergence, a sprinkler irrigation system was installed at the Fayetteville location, and at Pine Tree, the experiment was flood irrigated. At both locations, the experiments were irrigated when the estimated soil-moisture deficit (Purcell et al., 2007) reached 1.5 inches. At maturity, the ends of plots were removed, and 16 ft of the middle two rows were harvested. The moisture content of grain was corrected to 13%.

Economic Analysis. To determine the effect of added N fertilizer on soybean yield (Y), we regressed the average of replicated soybean yields by treatment in bu./ac against the amount of nitrogen applied (N) in lb/ac along with binary zero/one treatment effect variables to account for inoculant use (IN, 1 = seed inoculated and 0 = untreated seed), planting date (EP, 1 = early and 0 = late), location (LOC, 1 = Fayetteville and 0 = Pine Tree), and soybean seed maturity group (MG4, 1 = MG 4 and 0 = MG 5) treating year as a random effect as follows:

$$Y = a_0 + a_1 N + a_2\sqrt{\mathbf{N}} + a_3\,IN + a_4\,EP + a_5\,LOC + a_6\,N{\cdot}EP + a_7\,EP{\cdot}LOC + a_8\,MG4{\cdot}EP + a_9\,MG4{\cdot}LOC + \mu_t + \varepsilon \quad \text{Eq. 1}$$

where μ_t is the random year effect, ε is the error term and coefficient estimates (a) capture effects of explanatory variables on yield independent of production year. We employed EViews v. 9 (Lilien et al., 2015) using White's heteroscedasticity-consistent coefficient estimates using generalized least squares treating production year as a random rather than fixed effect on the basis of a Hausman test (Green, 2008).

The functional form of Eq. 1 was a result of choosing among square root and quadratic response functions for N. The final specification chosen was a result judging goodness of fit via adjusted R^2 and inclusion of variables with coefficient estimates that had t-statistics leading to added explanatory power (|t –stat| > 1.0).

Using the soybean yield response to N (Eq. 1), the effect of an added pound of N fertilizer in terms of added revenue per acre is:

$$\frac{\partial Y}{\partial N} \cdot P_Y = \left(a_1 + a_6{\cdot}EP + \frac{a_2}{2\sqrt{\mathbf{N}}}\right) \cdot P_Y \quad \text{Eq. 2}$$

where P_Y is the price received for soybean in \$/bu., and pending sign and size of coefficient estimates, marginal revenue declines with increasing N fertilizer use. On the other hand, fertilizer application charges are considered fixed in the sense that application rate will not affect the cost to apply the fertilizer (tractor, equipment, fuel, and labor are the same whether applying 5 or 10 lb of N fertilizer per acre, for example) and hence the marginal cost of increasing N fertilizer application rate is equal to the cost of N fertilizer in \$/lb (P_n). Hence, we solve for the profit-maximizing N application rate, N^*, by solving for the fertilizer rate where the marginal revenue generated is the same as it's marginal cost as follows:

$$\left(a_1 + a_6 \cdot EP + \frac{a_2}{2\sqrt{\mathbf{N}^*}}\right) \cdot P_Y = P_n \quad \text{or}$$

$$N^* = \left[\frac{2\left({}^{P_n}/_{P_Y} - a_1 - a_6 \cdot EP\right)}{a_2}\right]^{-2} \quad \text{Eq. 3}$$

As such, N^* will increase/decrease with higher/lower soybean price and increase/decrease with cheaper/more expensive N fertilizer. Further, N^* is impacted by planting date.

Results and Discussion

Table 2 summarizes the statistical results obtained using the 125 yield observations available. Adjusted R^2 indicates that approximately 84% of the variation in yield was explained by changes in the explanatory variables. Most explanatory variables had coefficient estimates that were statistically significant at $P < 0.05$. Exceptions were the interaction of *MG4* with *EP*, *N,* and $\sqrt{\mathbf{N}}$ but all had |t-stat.| > 1 indicating added explanatory power with inclusion.

Coefficient signs on *N* and $\sqrt{\mathbf{N}}$ and the interaction with *EP* led to yield response curves that showed a greater yield response to N, albeit small (y-axis only shows a range of 2 bu./ac), with early planting that plateaued near 57 lb/ac of N fertilizer, whereas yield-maximum occurred at 18 lb/ac of N fertilizer with late planting (Fig. 2). Noticeable with late planting is the steep descent in yield from the yield-maximizing rate. While interesting, the results are only marginally significant. The coefficient estimate for inoculant was highly significant; however, the sign on the coefficient estimate suggested that, on average, the use of inoculant led to a 1.3 bu./ac penalty. Hence, the use of this seed treatment was not found to be fruitful in this experiment.

Early planting leads to a sizable and statistically significant increase in yield, regardless of location. The Fayetteville location showed higher yields that were statistically significant. Finally, seed maturity group interactions with planting date and locations indicated higher yield with early planting and earlier maturing MG 4 soybean in Fayetteville. A similar impact of MG and planting date would be expected for the Pine Tree location, but the early planting date in 2017 was destroyed by heavy rains, and early planting in 2018 and 2019 was delayed until early- and mid-June, respectively.

Economically, inoculating soybean seed could be discouraged on the basis of the negative yield repercussions. N fertilizer use did indicate a positive yield response. With early planting, the use of N fertilizer led to an estimated yield boost near 1 bu./ac; whereas with late planting, that yield increase was only 0.5 bu./ac. As such, N fertilizer use, while yield-enhancing, could enhance profit only if fertilizer application charges were zero. At a custom charge of $7/ac, the revenue increase from higher yield with N fertilizer, at modest application rates was insufficient to pay for the cost of the fertilizer and the custom application charge. For example, at the profit-maximizing application rate of 8.4 lb N/ac with a soybean price of $15/bu. and urea at $0.4/lb N ($360/ton), a loss of $1.57 would result. With late planting, the profit-maximizing rate is less, leading to less added yield and thereby greater loss.

Using fertilizer or inoculant did not show statistically significant increases in yield in late-planted soybean in this experiment. Early planting, when possible and using earlier maturing soybean, especially in Fayetteville compared to Pine Tree, showed promising soybean yields. Hence, N fixation seems to be sufficient to support good soybean yield even without the use of inoculant. Nitrogen fixation is well known to decrease as the availability of mineral N in the soil increases, making the ability and consistency of obtaining a yield response to N fertilizer difficult (Salvagiotti et al., 2008).

Practical Applications

There was no apparent benefit from applying N fertilizer or of treating seed with inoculant in this study, although previous research has shown a benefit from inoculation when soybean was planted late. The research confirmed the yield advantage of early planting and the yield advantage of MG 4 cultivars over MG 5 for June planting dates.

Acknowledgments

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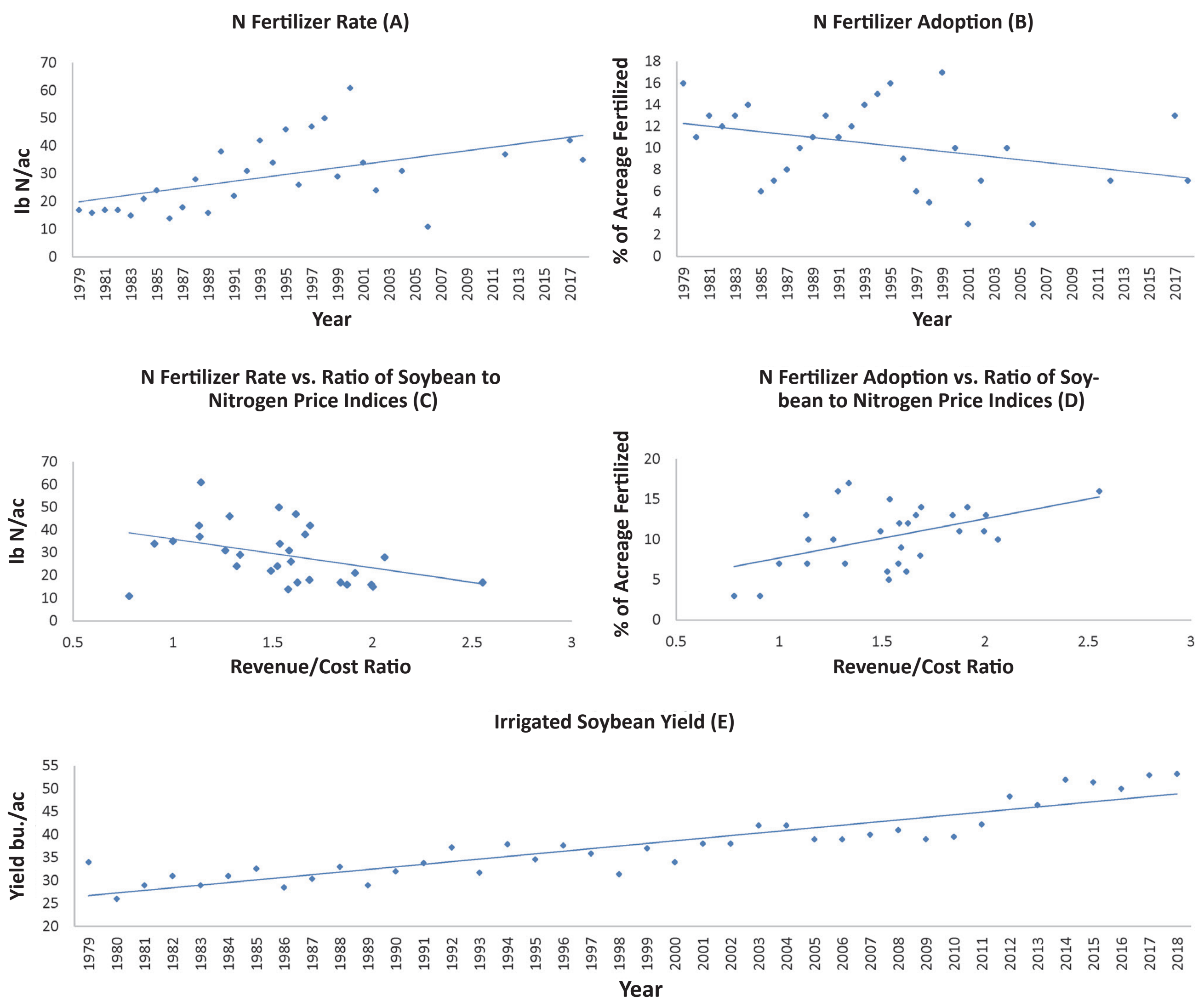

Fig. 1. Arkansas soybean N fertilizer rates, percentage of soybean acres fertilized with nitrogen and yield trend over time and in comparison to revenue/cost ratio (1979-2018 excluding 2003, 2005, 2007-2011, and 2013-2016).

Table 1. Soybean cultivars and planting dates by location and year.

	Soybean Maturity Group (MG)			Planting Dates			
	MG 4		MG 5	Early		Late	
Year	**FYV**[a]	**PT**	**FYV & PT**	**FYV**	**PT**	**FYV**	**PT**
2017	P47T36	na[b]	UA5715GT	10 June	na	28 June	N/A
2018	P47T36	P47T3 6	UA5715GT	18 May	5 June	14 June	10 July
2019	P48A60 X	P47T3 6	UA5715GT	11 June	15 June	27 June	N/A[c]

[a] FYV = the University of Arkansas System Division of Agriculture's Milo J. Shult Agricultural Research and Extension Center located in Fayetteville; and PT = University of Arkansas System Division of Agriculture's Pine Tree Research Station located near Colt, Arkansas.

[b] Excessive rainfall led to stand losses.

Table 2. Statistical results explaining soybean yield (*Y*) as a function of Nitrogen fertilizer application rate (*N*), as well as seed inoculation, planting date and location effects from 125 individual treatment observations of experimental trials conducted from 2017 to 2019 at the University of Arkansas System Division of Agriculture's Milo J. Shult Agricultural Research and Extension Center in Fayetteville and the Pine Tree Research Station near Colt, Arkansas. Statistical analysis was conducted using Generalized Least Squares treating production year as a random effect.

Dependent Variable	Y^a			
Explanatory Variables[b]		**Coefficient Estimate**	**Standard Error**	***P*-value**[c]
Constant	a_0	23.16	3.148	<0.001
N	a_1	-0.03	0.020	0.141
$\sqrt{N}$	a_2	0.25	0.181	0.171
IN	a_3	-1.33	0.541	0.016
EP	a_4	40.41	0.973	<0.001
LOC	a_5	28.64	0.643	<0.001
$N \cdot EP$	a_6	0.01	0.004	0.002
$EP \cdot LOC$	a_7	-39.45	0.579	<0.001
$MG4 \cdot EP$	a_8	7.01	3.935	0.077
$MG4 \cdot LOC$	a_9	9.12	4.671	0.053
Adj. R^2	0.84			

[a] Soybean yield in bu./ac.

[b] N application rate (*N* in lb/ac), inoculant use (IN, 1 = seed inoculated and 0 = untreated seed), planting date (EP, 1 = early and 0 = late), location (LOC: 1 = Fayetteville and 0 = Pine Tree), and soybean seed maturity group (MG4, 1 = MG 4 and 0 = MG 5).

[c] *P*-values were calculated using White's heteroscedasticity-consistent covariances.

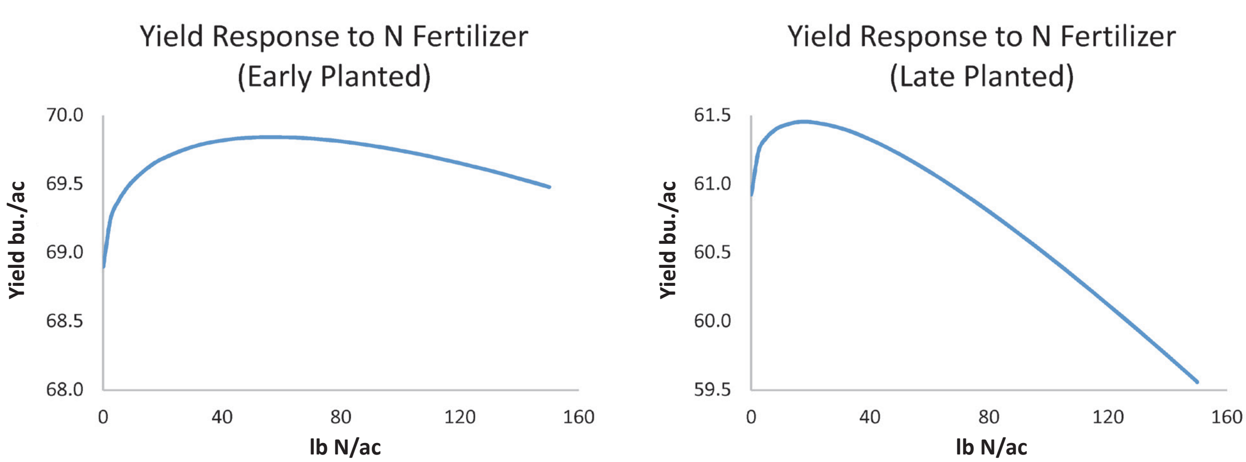

Fig. 2. Estimated yield response as impacted by planting date regardless of inoculant use with yield estimates for plots at the University of Arkansas System Division of Agriculture's Milo J. Shult Agricultural Research and Extension Center in Fayetteville, Arkansas without inoculant.

Soybean Yield Influenced by Winter Wheat and Cover Crop Species

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Abstract

Due to it being a vital rotational crop, soybean [*Glycine max* (L.) Merr.] accounts for over 50% of Arkansas crop acres annually. With an increased interest in planting cover crops across the state, it is important to evaluate the influence that a winter cover crop can have on a successive soybean crop and compare the yields of wheat (*Triticum aestivum*) soybean double-cropped system as well as a winter fallow. This study evaluated the following: winter fallow, winter wheat for grain, cereal rye (*Secale cereale*), black-seeded oat (*Avena sativa*), barley (*Hordeum vulgare*), Austrian winter pea (*Pisum sativum*), blue lupin (*Lupinus angustifolius*), Blend 1 (cereal rye, crimson clover (*Trifolium incarnatum*), seven-top turnip (*Brassica rapa*)), and Blend 2 (black oats and Austrian winter pea). Trials were established at the University of Arkansas System Division of Agriculture's Vegetable Research Station (VRS), Rohwer Research Station (RRS), and Pine Tree Research Station (PTRS). At VRS and PTRS, soybean planting following winter wheat harvest was delayed, and decreased soybean yields were observed as a result; however, at RRS, soybean following winter wheat was planted during the optimal window, and optimal yields were observed. Each of these practices can be successful, but the location within the state affects each practice differently. Soybean yields following each winter treatment were highly dependent upon the location within the state. The southernmost location showed no reduction in soybean yield following winter wheat, whereas the more northern locations saw significantly lower yields following winter wheat. The data indicate that double-cropped soybean is still an economically feasible practice in the southernmost portion of the state, and cover crops offer a promising alternative for the majority of the state.

Introduction

In Arkansas, a majority of winter wheat is grown in a double-cropped system. The winter wheat is harvested on average around 7 June and is immediately followed by the planting of a soybean crop. Soybean is commonly planted between mid-May and early June. Because the average winter wheat harvest date is 7 June, soybean grown in a double-cropped system is planted in the latter part of the optimal planting window or delayed beyond that (Ashlock et al., 2000). Hu and Wiatrak (2012) found that as soybean planting date is delayed beyond the optimal planting window, producers begin seeing decreases in soybean yield due to photoperiod effects, as well as temperature and precipitation effects. Yield typically decreases 1%–2% per day as planting is delayed past 15 June and can decrease up to 2%–3% per day once 1 July is reached (Ashlock et al., 2000). Arkansas is seeing a steady decline in the number of acres used for double-cropped winter wheat and soybean. Harvesting two cash crops on the same land within a year meant the double-cropping practice was a highly profitable one for Arkansas producers. With the price of wheat now fluctuating around \$4–5/bushel and producers seeing decreasing soybean yields due to delayed planting, this practice is no longer economically feasible. With the decreasing acres of double-cropped soybean, producers are instead becoming increasingly interested in winter cover crops. Research has shown that cover crops provide benefits such as decreased soil erosion and pest suppression (Snapp et al., 2005). Little research has been done within the state of Arkansas that focuses on the effects that winter cover crop species have on the yield of a subsequent soybean crop, and that also compares soybean following cover crops to that of a traditional wheat-soybean double-cropped system seen in the state.

Procedures

This experiment was conducted in 2018 and 2019 at three University of Arkansas System Division of Agriculture research stations: Vegetable Research Station (VRS) near Kibler, Ark., the Rohwer Research Station (RRS) near Rohwer, Ark., and the Pine Tree Research Station (PTRS) near Colt, Ark. For this research, a no-till system was maintained, and each trial was planted on a silt loam soil. Soy-

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bean seeding rate, irrigation, and pest management followed recommendations from the University of Arkansas System Division of Agriculture's Cooperative Extension Service (UACES, 2000).

Various winter cover crops were evaluated in this study, including five single species, two blends, winter wheat harvested for grain, and a winter fallow. The single species cover crops included Austrian winter pea (*Pisum sativum*), barley (*Hordeum vulgare*), black-seeded oats (*Avena sativa*), blue lupin (*Lupinus angustifolius*), and cereal rye (*Secale cereale*). Blend 1 consisted of cereal rye, crimson clover (*Trifolium incarnatum*), and seven-top turnip (*Brassica rapa*). Blend 2 was a mixture of black-seeded oats and Austrian winter pea. Cover crops and winter wheat were drill-seeded with a row spacing of 7.5-in. in the fall of 2018 and again in the fall of 2019 with a no-till drill at various seeding rates according to recommendations from the University of Arkansas System Division of Agriculture's Cooperative Extension Service (Roberts, 2018). Cover crop seeding rates are listed in Table 1. Cover crops were chemically terminated at approximately early heading to ensure that maximum biomass accumulation was achieved. The single grass species were terminated using glyphosate at a rate of 15.6 fl oz ai/ac. The single legume species, as well as the two blends, were terminated using a mixture of metribuzin (4.5 fl oz ai/ac) and paraquat (14.4 fl oz ai/ac) (Palhano et al., 2015).

Soybean was drill seeded approximately 3–4 weeks after the termination of cover crops to break the green bridge per the Cooperative Extension Service recommendations. Soybean following winter wheat was planted directly following wheat harvest. Soybean row width ranged from 7.5 to 38-in. (Table 2) depending on location and available planting equipment. Following soybean emergence, stand counts were taken to ensure proper plant population was achieved to produce optimal yields.

Using a small plot combine, soybean plots were harvested in 140-ft strips and grain yield was adjusted to 13% moisture. Winter wheat was also harvested with a small plot combine in 35-ft strips and adjusted to 13% moisture.

Each experiment was a randomized complete block design with four blocks. All yield data were subjected to analysis using JMP 14.0 (SAS Institute, Inc., Cary, N.C.). A one-way analysis of variance (ANOVA) was performed with winter crop as the treatment and means were separated using a Tukey-Kramer honestly significant difference (HSD) with an alpha level of 0.05. Treatments were compared within locations due to different planting dates and environmental conditions throughout the state.

Results and Discussion

In the fall of 2017, conditions were optimal for planting cover crops, allowing timely planting within the appropriate cover crop planting window. This timely planting allowed for optimal cover crop growth leading to maximum benefits observed in the following soybean crop. At VRS, there was no significant effect of the various cover crop species or fallow on the following soybean yields; however the yield of the soybean following the winter wheat was significantly lower than all other treatments ($P < 0.0001$) (Table 3). At PTRS, soybean following both barley and Blend 2 was significantly higher yielding than the soybean following winter fallow and winter wheat, but they were not significantly different from the other cover crop treatments ($P = 0.0002$) (Table 3). The significantly lower soybean yields following the winter wheat treatment were a direct result of the later planting date of the double-cropped soybean than the planting date of the soybean following the cover crop treatments and the winter fallow. At RRS, which is located in the southeastern region of Arkansas, there were no differences in the soybean yields following each of the treatments (Table 3). This is a direct result of location and growing season. Because this trial was located in southern Arkansas, the winter wheat reached maturity sooner and was harvested on 24 May 2018, as compared to the northern locations, PTRS and VRS, which were harvested on 8 June 2018 and 12 June 2018 respectively. The delayed winter wheat maturity at PTRS and VRS lead to delayed planting of the following soybean crop.

In the fall of 2018, planting conditions were suboptimal. Due to excessive precipitation, soil moisture remained too high to plant during the optimal cover crop and winter wheat planting window, leading to delayed planting and prevented planting at some locations. There was no winter wheat planted at RRS or PTRS due to this excessive fall rainfall. Due to conditions, winter wheat planting was delayed, so a forage variety was planted and was not harvested for grain, which served as a winter wheat cover crop treatment. Cover crops at VRS were planted 30 Nov., at PTRS they were delayed until 21 March 2019, and cover crops were unable to be planted at the RRS location. Research performed by Roberts et al. (2015) determined that fewer benefits are seen in a soybean crop following delayed planted cover crops than following cover crops planted in an optimal window.

At both VRS and PTRS, there were no significant differences in soybean yield following each of the treatments. At RRS, soybean following winter wheat yielded approximately the same as black-seeded oats and blue lupin but yielded significantly higher than all others ($P < 0.0001$) (Table 4). Because no cover crops or winter wheat were planted at this location in the fall of 2018, the differences seen in the 2019 soybean crop can be attributed to carry-over effects from the previous year's treatments, such as increased soil organic matter.

Practical Applications

Based on the results of this study, location within the state significantly impacts whether or not a producer should keep the traditional system of double-cropping winter wheat and soybean or if the producer should switch to cover crops as an alternative. Switching to cover crops can maximize yield and profit while also allowing for advantages to be seen from the continuous ground cover. Locations at or south of Rohwer, Ark. are suitable for a double-cropping system that allows for optimum yields of both the wheat and the soybean in the system. In locations north of Rohwer, Ark. cover crops offer the same benefits that can be seen with double-cropping while allowing for maximum yield potential and profits in a successive soybean crop. Cover crop and winter wheat planting dates also play a vital role in these systems. At locations in which cover crops and winter wheat were delayed, the soybean yield following these treatments was no different from the fallow treatment.

Acknowledgments

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Table 1. Seeding rate for each winter crop treatment.

Crop Species	Drilled Seeding Rate
	------------------lb/ac-----------------
Austrian Winter Pea	35
Barley	45
Black-Seeded Oat	40
Blue Lupin	50
Cereal Rye	40
Blend 1	40
Blend 2	40
Winter Wheat	100

Table 2. Management information and seeding dates for winter wheat, cover crops, and soybean for 2017–2019.

Information	Pine Tree Research Station (PTRS)	Rohwer Research Station (RRS)	Vegetable Research Station (VRS)
Soil Series	Calloway Silt Loam	McGehee Silt Loam	Roxanna Silt Loam
Cover Crop Row Spacing (in)	7.5	6	7.5
Soybean Row Spacing (in)	15	38	7.5
Soybean Seeding Rate	150,000 seeds/ac	150,000 seeds/ac	150,000 seeds/ac
2018 Soybean Seeding Date following Cover Crops	19 April	1 May	12 June
2018 Soybean Seeding Date following Winter Wheat	18 June	25 May	3 July
2019 Soybean Seeding Date following Cover Crops	4 June	16 May	21 June
2019 Soybean Seeding Date following Winter Wheat	23 May	16 May	14 May
2017 Winter Treatment Seeding Date	11 December	19 December	18 December
2018 Winter Treatment Seeding Date	19 March 2019	-	30 November

Table 3. 2018 soybean yield as influenced by winter crop treatment for each trial location.

Treatment	Pine Tree Research Station (PTRS)	Rohwer Research Station (RRS)	Vegetable Research Station (VRS)
	----------------------Yield (bu./ac)---------------------------------		
Austrian Winter Pea	57 ab†	74 a	59 a
Barley	61 a	68 a	54 a
Black-Seeded Oat	52 abc	73 a	54 a
Blue Lupin	56 ab	68 a	58 a
Cereal Rye	54 abc	68 a	53 a
Blend 1	56 ab	72 a	55 a
Blend 2	60 a	74 a	55 a
Winter Wheat	35 c	70 a	27 b
Fallow	47 bc	67 a	59 a

†Means followed by the same letter are not significantly different.

Table 4. 2019 soybean yield as influenced by winter crop treatment for each trial location.

Treatment	Pine Tree Research Station (PTRS)	Rohwer Research Station (RRS)	Vegetable Research Station (VRS)
	-------------------------------Yield (bu./ac)--------------------------------------		
Austrian Winter Pea	62 a†	60 b	59 a
Barley	64 a	61 b	57 a
Black-Seeded Oat	58 a	63 ab	60 a
Blue Lupin	63 a	64 ab	53 a
Cereal Rye	64 a	58 b	56 a
Blend 1	64 a	63 b	54 a
Blend 2	65 a	61 b	59 a
Winter Wheat	59 a	75 a	-
Fallow	62 a	58 b	52 a

†Means followed by the same letter are not significantly different.

Short-Term Influence of Winter Cover Crops on Soybean Yield in a Corn-Soybean Rotation

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Abstract

Soybean production is a vital aspect of Arkansas' economy and agriculture as it makes up most row crop acres. Soybean is the main rotational partner to many other crops such as corn, cotton, and rice. Therefore, improving the efficiency of soybean production is imperative to the longevity of this important crop. Cover crops could provide a boost to the sustainability of soybean production via the plethora of benefits they provide, such as improved weed suppression, water infiltration/retention, nutrient cycling, and so on. Understanding the influence these cover crops have on soybean yield is important to the adoption of this practice. The objective of this study was to determine the short-term influence cover crops have on soybean yield in a corn-soybean rotation. This experiment was conducted at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS) near Colt, Ark. Four cover crop treatments included cereal rye (*Secale cereal*), Austrian winter pea (*Pisum sativum*), a mixture of black-seeded oat (*Avena sativa*) and Austrian winter pea provided by the Soil Health Recommendation (SHR) tool, and an annual alternation of cereal rye (prior to soybean) and Austrian winter pea (prior to corn). In all years except 2019, there were no significant differences among cover crop treatments. In 2017 and 2018, cover crops provided a significant yield increase when compared to the fallow treatment. In 2019 yields were not significantly different among any treatment, including fallow. Yields were slightly lower than in previous years due to wet weather and delayed planting.

Introduction

Soybean production makes up a large portion of Arkansas agriculture. Soybean accounts for the majority of row crop areas, a result of its compatibility as a rotational partner to other cash crops such as corn, cotton, and rice. Improving the sustainability of soybean production via reduced input cost (i.e., synthetic fertilizers, irrigation, tillage, etc.) and environmental impact is important to the long-term success of Arkansas row crop producers. Cover-cropping has become a staple in sustainable agriculture discussion. Cover crops can provide a variety of benefits such as reduced erosion and surface-water runoff, improved weed suppression, increased soil organic matter, and benefits to various soil quality characteristics (Blanco-canqui, 2018; Khanh et al., 2005; Raimbault et al., 1990). Introducing cover crops into production, however, does not come without challenges. According to Myers (2019), less than 6% of row crop utilizes cover cropping in Arkansas, a result of a general lack of research and understanding of the effect of cover-crops on production and the agronomical hurdles producers will face. Determining the influence that various cover crops have on yield in the few years after the introduction is important in the adoption and success of cover cropping and must be addressed.

Procedures

This study was conducted as a part of a long-term trial established at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS) during the fall of 2015. The area in which this study was conducted was brought out of commercial agriculture production. Raised beds spaced 30-in. apart were established in which corn and soybean were rotated annually using no-till furrow irrigation practices. In the first year of the study (2016), no cover crops were seeded before cash crops to obtain a baseline of production. Cash crops (corn-soybean) were rotated annually to capture the rotational effect commonly utilized in Arkansas production following the 2016 harvest. In the fall, cover crops were drill-seeded at 6-in. spacing over cash crop beds (Table 1). Cover crop treatments included 2 mono-cultures and 1 mixture as well as a fallow check; cover crops were seeded as early as possible following cash crop harvest in the fall (Table 2). To capture maximum coverage of the cover crop treat-

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ment, plots were 8 rows wide (20 ft) and 240-ft long. Chemical termination was approximately 2–4 weeks before cash crop planting as per the University of Arkansas System Division of Agriculture's Cooperative Extension Service recommendations. Cover crops were terminated using metribuzin and paraquat before soybean at a rate of 2.5 oz ai/ac and 14 oz ai/ac, respectively (Palhano et al., 2018). Soybean was no-till planted at approximately 150,000 seed/ac. Soybean received an in-season rate of K_2O and P_2O_5 as recommended by the University of Arkansas System Division of Agriculture's soil test and was furrow irrigated as needed based on the Arkansas irrigation scheduler set to a 1.5 in. deficit (Tacker and Vories, 2000; Slaton et al., 2013). The inside two rows were harvested and adjusted to 13% moisture for grain yield.

This experiment was arranged in a randomized complete block design (RCBD) with four blocks. A simple one-way analysis of variance (ANOVA) was run to find significance between cash crop yield and cover crop treatment. Once significance was found, a Tukey-Kramer honestly significant difference test ($\alpha = 0.05$) was used to separate yield means among cover crop treatment. The statistical analysis was completed using JMP Pro 14.0.

Results and Discussion

The ANOVA indicated there to be significant interactions between cover crop and soybean yield in all years except for 2019. In this study, soybean yields were not compared between years due to external factors such as environmental changes throughout the growing season from year to year, as well as changes in cash crop varieties used for each year. In 2016 the baseline average yield was 55 bu./ac (Table 3). This was following no cover crop treatment in the fall of 2015. In the first year of cover crop implementation (2016–17), soybean yield was significantly higher with a 4 bushel difference following the mixture of black-seeded oat and Austrian winter pea than the fallow treatment, yielding 53 bu./ac and 49 bu./ac, respectively. All cover crop treatments in 2017 were not statistically different; however, the mixture did provide a slight improvement to a traditional no-till fallow system when compared to the other cover crops. In 2018, soybean yields maintained similar levels to that of 2016 and 2017, however yields following Austrian winter pea and cereal rye were statistically higher than fallow and the Soil Health Recommendation (SRH) mixture. Soybean following Austrian winter pea and cereal rye in the annual alternation yielded 61 and 60 bu./ac, respectively, roughly 10 bushels higher than fallow and the SHR mixture, both at 51 bu./ac. The alternating cover crop treatment may have a residual influence of previous Australian Winter Pea (AWP) years before corn that could influence the subsequent soybean yield. Soybean in 2018 yielded higher in the rotational treatment containing cereal rye over the mono-culture cereal rye treatment by 6 bu./ac; though not statistically different it is a substantial change. This may indicate some rotational benefit with the additional legume in the alternating treatment that would have been planted before corn in 2017. Further research is needed to quantify the significance or insignificance of this effect. Austrian winter pea likely added nitrogen (N) credits to the soil via N fixation, providing additional nutrient availability in the early growth stages, improving stand quality, and subsequently yield. Despite seeing this yield gain following AWP, it would not be recommended to follow a legume cover crop with a legume cash crop. Continued mono-culture could set up for crop failure in terms of disease and insect pressure.

Proper termination timing and disruption of the "green bridge" is vital for cover crop success in Arkansas' climate production system. In 2019 weather delayed planting of both the cover crops and cash crops. With delayed planting, we saw lower yields than previous years; however, we saw no significant differences among all cover crop treatments and fallow. Yield averages varied from 45 bu./ac following SHR mix to 51 bu./ac following cereal rye in 2019. Overall, soybean was fairly resilient to changes with the implementation of cover crops; in all years, we saw either a positive effect or no effect when comparing cover crop treatments to a fallow check. This effect has also been seen in previous literature (Archaya et al., 2020).

Practical Applications

Maximizing the benefits of cover crops depends on the goal of the producer. As this data indicates, there is no outstanding cover crop treatment that provided consistent yield improvements from year to year. However, yields maintained relatively stable levels when looking back to the baseline yield of 55 bu./ac in 2016 and the state average of 49 bu./ac (USDA-NASS, 2019). Utilizing a cover crop to improve various aspects of soybean production such as weed suppression, water retention/infiltration, improving soil organic matter, etc. should be the focus of producers when implementing cover crops. Cover crops will likely not provide a yield increase in the first few years of use; however, over time profitability of soybean production may improve via the benefits cover crops provide. Continued research evaluating the benefits of cover crops may give insight into which cover crops need to precede a soybean crop, leading to cover crop recommendations for Arkansas producers.

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Table 1. Cover crop species and seeding rates.

Treatment	Species	Seeding Rate
		---------lb/ac ---------
Fallow	N/A	N/A
AWP	Austrian winter pea	30-55
Alt CC	Cereal rye (prior to soybean)	35-50
CR	Cereal rye	35-50
SHR	Black-seed oat: Austrian winter pea 40:60	40-55

N/A = Not available.

Table 2. Cash crop and cover crop planting dates.

Year	Cover Crop Planting Date	Cover Crop Replant Date	Soybean Planting Date
2016	N/A	N/A	14 April
2017	12 October	N/A	10 May
2018	30 October	21 March	19 April
2019	20 October	N/A	4 June

N/A = Not available.

Table 3. Soybean yield following cover crop treatments.

Treatment	2016	2017	2018	2019
	------------------------------------Yield (bu./ac)------------------------------------			
CR‡	N/A	50 ab	54 ab	51 a
AWP‡	N/A	52 ab	61 a	48 a
SHR‡	N/A	53 a	52 ab	45 a
Alt CC‡	N/A	52 ab	60 a	47 a
Fallow	55	49 b	51 b	49 a

† Means followed by the same letter within a column are not significantly different at $P = 0.05$.

‡ CR = Cereal rye; AWP = Austrian winter pea; SHR = Soil Health Recommendation = Black-seeded oats: Austrian winter pea, 40:60 mixture ratio; AltCC = Alternating cover crop.

N/A = Not available.

Runoff Water Quality from Soybean Production: A Summary of Results from the Arkansas Discovery Program

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Abstract

The overall goal of the Arkansas Discovery Farms program is to assess the need for and effectiveness of on-farm conservation practices, document nutrient and sediment loss reductions, soil health, and water conservation in support of nutrient management planning and sound environmental farm stewardship. Utilizing state-of-the-art edge-of-field runoff monitoring on several commercial row crop farms in Arkansas, 442 water samples were collected from 19 different fields beginning in 2013 and continuing through 2019 representing 38 site years. Median values across all sites and years for nitrate (NO_3^-), total nitrogen (TN), soluble reactive phosphorus (SRP) and total phosphorus (TP) were 0.32, 1.54, 0.19 and 0.44 mg/L, respectively. These results indicate relatively low concentrations that are similar to median values from streams in agricultural watersheds across the country. This implies that soybean producers that cooperated in this study closely and consistently matched fertilizer needs to crop needs so that there were only small amounts of fertilizer nutrients [phosphorus (P) and nitrogen (N)] available to be transported via runoff from the field following application. Overall, Discovery Farm studies have indicated that less than 5% of N and P applied as fertilizer leaves the field in surface runoff.

Introduction

Row crop producers in the Lower Mississippi River Basin (LMRB) are under increased scrutiny to demonstrate that current production systems are environmentally viable for water quality and sustainability (Daniels et al., 2018). These concerns are manifested from regional issues such as hypoxia in the Gulf of Mexico (USEPA, 2018a) and critical groundwater decline in Lower Mississippi Alluvial Valley aquifer (LMAV), (Reba et al., 2017; Czarnecki et al., 2018).

Nutrient enrichment remains a major impairment of water quality to the designated uses of fresh and coastal waters of the U.S. (Schindler et al., 2008). Nutrient runoff from cropland is receiving greater attention as a major source of nutrients from nonpoint sources (Dubrovsky et al., 2010). This is especially true in the Mississippi River Basin (MRB), as recent model estimates suggest that up to 85% of the phosphorus (P) and nitrogen (N) entering the Gulf of Mexico originates from agriculture (Alexander et al., 2008). These estimates are based on large-scale modeling within the MRB, with limited localized calibration or verification of the field losses of P and N. Furthermore, there have been few farm-scale studies of P and N loss, particularly in the LMAV region of agriculture-dominant Arkansas and Mississippi (Dale et al., 2010; Kröger et al., 2012).

This scrutiny has prompted much activity aimed at reducing nutrients lost to the Gulf within the Mississippi River Basin, including the formation of the Mississippi River/Gulf of Mexico Hypoxia Task Force, a consortium of Federal agencies and States (USEPA, 2018a). This consortium developed an action plan to reduce nutrients entering the Gulf, which includes nutrient reduction strategies prepared by each member state (USEPA, 2018b).

Arkansas Discovery Farms are privately owned farms that have volunteered to help with on-farm research, verification, and demonstration of farming's impact on the environment and natural resource sustainability (Sharpley et al., 2015, 2016).

The overall goal of the program is to assess the need for and effectiveness of on-farm conservation practices, document nutrient and sediment loss reductions, and water conservation in support of nutrient management planning and sound environmental farm stewardship. Edge-of-field monitoring (EOFM) of runoff from individual agricultural fields is critical to improving our understanding of the fate and transport of nutrients applied as animal manures and fertilizer to agricultural lands along the complex watershed continuum (Reba et al., 2013; Harmel et al., 2016; Sharpley et al., 2016).

Additionally, EOFM helps producers more clearly see how their management systems affect in-stream water quality

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and watershed functions (Sharpley et al., 2015). The objective of this paper was to provide a summary of nutrient loss from soybean production across all years, locations, and production practices to provide quantification of nutrient losses from soybean production.

Procedures

Edge-of-field runoff monitoring stations were established on several commercial farms in Arkansas, Cross, Jefferson, Pope, and St. Francis counties of Arkansas. From 2013 to 2019, 442 water samples were collected from 19 different fields equipped with EOFM stations representing 38 site years.

At the lower end of each field, automated, runoff water quality monitoring stations were established to 1) measure runoff flow volume, 2) collect water quality samples of runoff for water quality analysis, and 3) measure precipitation. Either a 60-degree, V-shaped, eight-inch trapezoidal flume that pre-calibrated and gauged was installed at the outlet of each field, or if an existing drainage pipe served as the outlet, it was instrumented (Tracomm, 2018). The ISCO 6712, an automated portable water sampler (Teledyne-ISCO, 2018), was used to interface and integrate all the components of the flow station. Where flumes were used, an ISCO 720 pressure transducer and flow module were used. For existing drainage pipes, an ISCO 750 area velocity meter and flow module were utilized.

All samples were analyzed at the Arkansas Water Resources Laboratory (Arkansas Water Resources Center, 2018), an EPA-certified laboratory, for total nitrogen (TN), nitrate + nitrite-N (NO_3^-), total phosphorus (TP) and soluble reactive phosphorus (SRP).

Results and Discussion

The summary of nutrient concentrations for NO_3^-, TN, SRP, and TP across all years and locations greatly varied, while median values were relatively low (Table 1). The data indicated highly skewed data as expected as it represents all sites and years and the associated management practices.

For this reason, the median values of 0.32, 1.54, 0.19, and 0.44 mg/L for NO_3^-, TN, SRP, and TP, respectively, were used to describe central tendency rather than the mean. To put these values in perspective, Dubrosky (2010) reported median concentrations of 4 mg/L and 0.24 mg/L of TN and TP, respectively for samples collected from agricultural watersheds from all over the United States during 1993–2004 by the United States Geological Survey (USGS). The median of TN data collected in Arkansas was lower than the USGS stream data; however, the median TP data collected in Arkansas was slightly higher.

However, runoff volume from an individual field may be much lower than the volume of water in a major stream or river.

Nutrient concentrations also varied at a given site by year (Figs. 1, 2, and 3), depicting the effect that the varying nature of hydrological events can have on nutrient losses.

Practical Applications

Data from EOFM can help provide perspective on agricultural's impact on water quality in terms of nutrient losses. Our data indicate relatively low concentrations that are similar to median values from streams in agricultural watersheds across the country. This implies that soybean producers that cooperated in this study closely and consistently matched fertilizer needs to crop needs so that there were only small amounts of fertilizer nutrients (P and N) available to be transported via runoff from the field following application.

Overall, Discovery Farm studies have indicated that less than 5% of N and P applied as fertilizer leaves the field in surface runoff. The fact that much of Arkansas' row crops are grown on long rows with very little slope helps reduce energy associated with runoff so that transport is dampened or reduced.

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Table 1. Statistics of all concentration data from runoff water on Discovery Farms fields growing soybeans from 2013 through 2019 (number of samples included in analysis = 442).

Attribute	Nitrate+Nitrite-N	Total Nitrogen	Soluble Reactive Phosphorus	Total Phosphorus
	mg/L	mg/L	mg/L	mg/L
Mean	0.780	2.36	0.375	0.781
S.D.	2.164	3.41	0.477	1.069
C.V. (%)	277.4	144.7	127.0	136.8
Minimum	0	0.05	0.002	0.024
Max	30.160	36.97	2.937	10.460
Median	0.321	1.54	0.188	0.442

S.D. = Standard deviation; C.V. = Coefficient of variation.

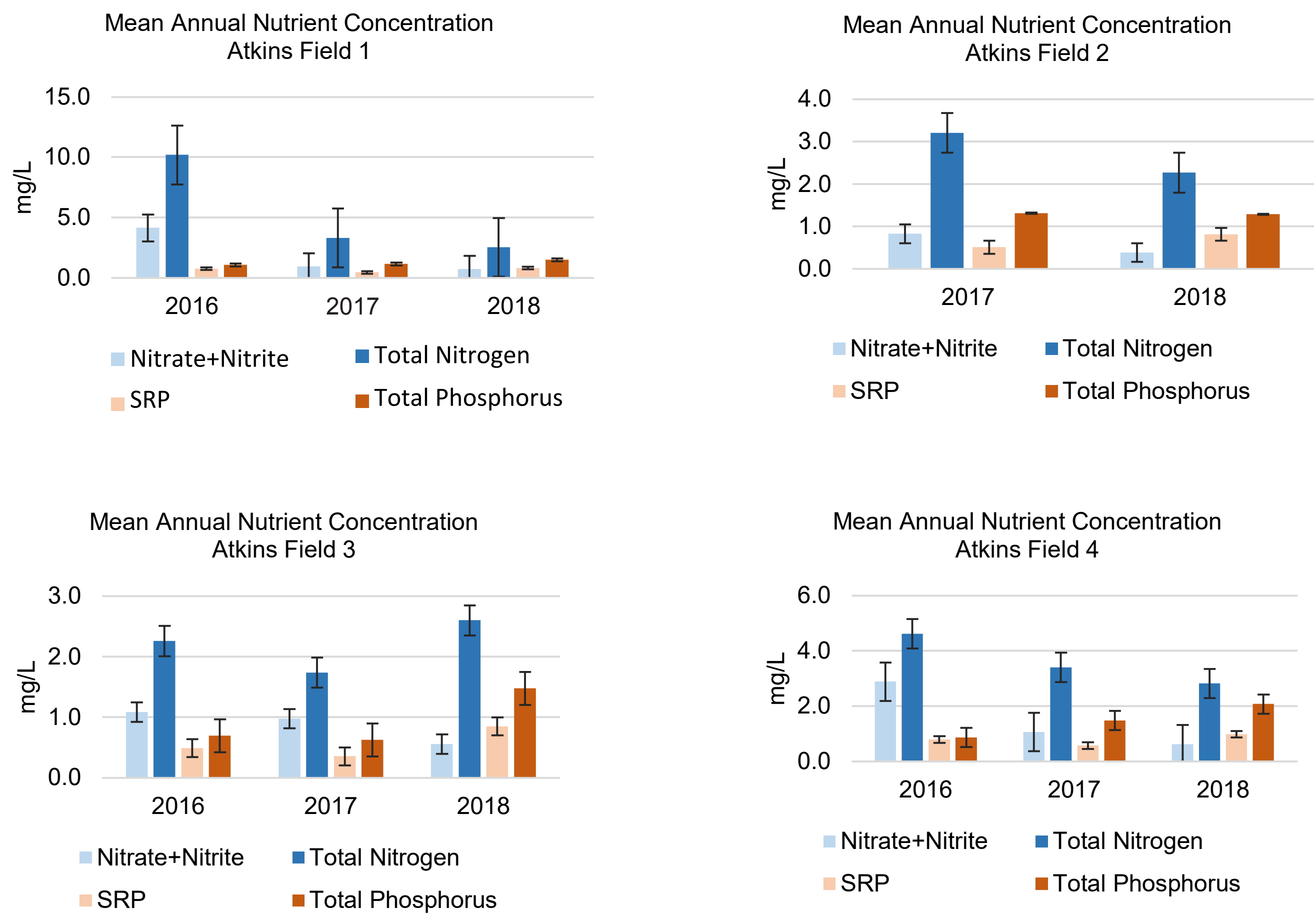

Fig. 1. Mean nutrient concentration (mg/L) in runoff averaged across all runoff events by year for different side-by-side fields in Pope County. SRP = soluble reactive phosphorus.

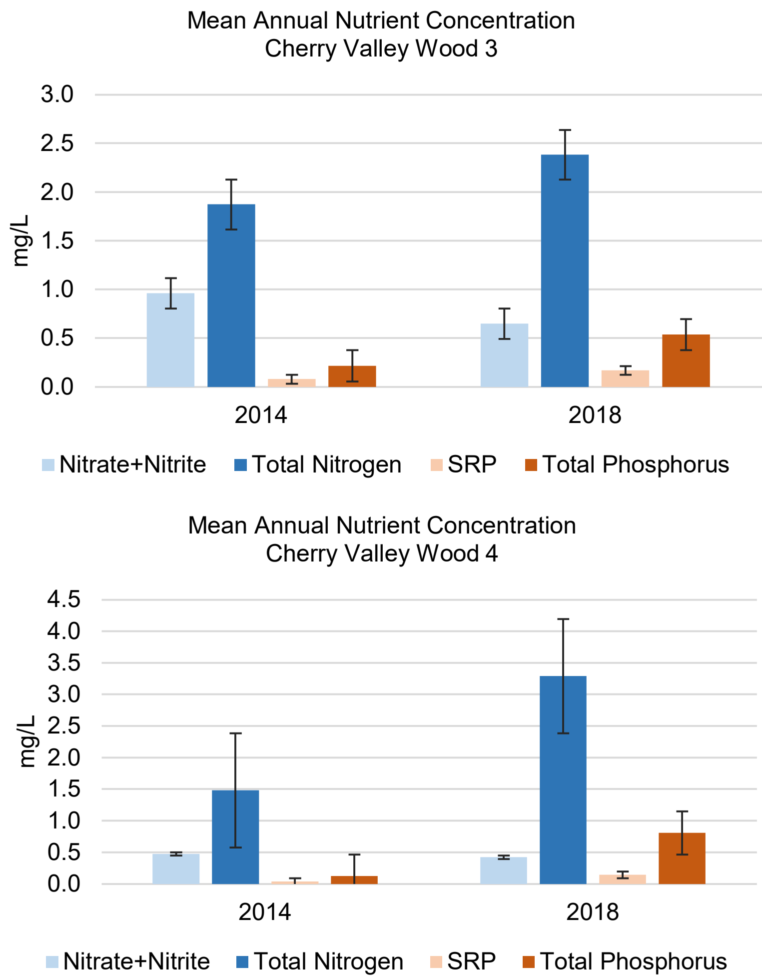

Fig. 2. Mean nutrient concentration (mg/L) in runoff averaged across all runoff events by year for different side-by-side fields in Cross County. SRP = soluble reactive phosphorus.

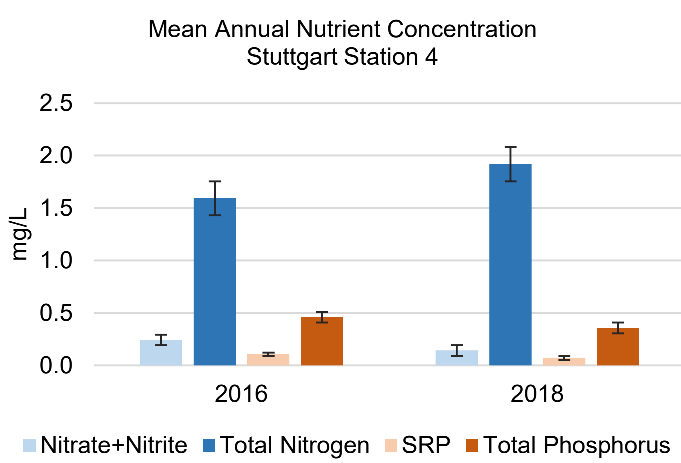

Fig. 3. Mean nutrient concentration (mg/L) in runoff averaged across all runoff events by year for different side-by-side fields in Arkansas County. SRP = soluble reactive phosphorus.

Developing Profitable Irrigated Rotational Cropping Systems

J.P. Kelley[1] and T.D. Keene[1]

Abstract

A large-plot field trial evaluating the impact of crop rotation on yields of winter wheat (*Triticum aestivum* L.) and irrigated corn (*Zea mays* L.), early planted soybean [*Glycine max* (L.) Merr], double-crop soybean, full-season grain sorghum [*Sorghum bicolor* (L.) Moench] and double-crop grain sorghum was conducted from 2013–2019 at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station near Marianna, Arkansas. When compared to yields of continuously grown soybean, April planted group 4 soybean yields were greater in 3 out of 6 years when following corn or full-season grain sorghum, averaging 6 and 8 bu./ac, respectively. Crop rotation impacted June planted double-crop soybean yield 1 out of 6 years, and average yields were 4 bu./ac greater when following corn or grain sorghum than a previous double-crop soybean crop. Corn yields were impacted by the previous crop 1 out of 6 years, where corn following corn yield was 26 bu./ac lower than when following April planted soybean in 2016. On average, corn following corn yielded 6 and 7 bu./ac less than when following April planted soybean or double-crop soybean, respectively. Wheat yields were impacted by the previous crop in 3 out of 5 years of the trial. Wheat following full-season grain sorghum across all years yielded 7 bu./ac less than when following April planted soybean, and 4 bu./ac less when following corn or double-crop soybean. Full-season grain sorghum was always planted following April planted soybean or double-crop soybean, and yields averaged 114 bu./ac with no difference in yield between previous crops. Double-crop grain sorghum averaged 87 bu./ac across all years.

Introduction

Arkansas crop producers have a wide range of crops that can be successfully grown on their farms, including early-season group 4 soybean (typically planted in April), corn, full-season grain sorghum, wheat, double-crop soybean, double-crop grain sorghum, cotton, and rice depending on soil classification. As crop acreages in Arkansas have changed over the years due to grain price fluctuations and changing profitability, more producers are incorporating crop rotation as a way to increase crop yields and farm profitability. Crop rotation has been shown in numerous trials to impact crop yields. In studies near Stoneville, Miss., Reddy, et al., 2013, found that corn yields following soybean were 15%–31% higher than when corn was continuously grown; however, soybean yields were not statistically greater, but trended to higher yields when planted following corn. In Tennessee, Howard et al., 1998, found that soybean following corn yielded 11% higher than compared to continuous soybean and attributed soybean yield increases following corn to reduced levels of soybean-cyst nematodes. As crop acreage continues to shift based on economic decisions, more information is needed for producers on which crop rotation produces the greatest yields and profitability under mid-South irrigated conditions. There is a lack of long-term crop rotation research that documents how corn, soybean, wheat, and grain sorghum rotations perform in the mid-South. A comprehensive evaluation of crop rotation systems in the mid-South is needed to provide non-biased and economic information for Arkansas producers.

Procedures

A long-term field trial evaluating yield responses of eight rotational cropping systems that Arkansas producers may use was initiated at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station near Marianna, Arkansas in April of 2013. The following eight crop rotations were evaluated:

1. *Corn/Soybean/Corn/Soybean*. Corn planted in March or April each year followed by early-planted group 4 soybean planted in April the following year.
2. *Corn/Wheat/Double-Crop Soybean/Corn.* Corn planted in March or April, followed by wheat planted in October following corn harvest, then double-crop soybean planted in June after wheat harvest, and corn planted the following April.

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3. *Wheat/Double-Crop Soybean/Wheat.* Wheat planted in October, followed by double-crop soybean planted in June, then wheat planted in October.
4. *Full-Season Grain Sorghum/Wheat/Double-Crop Soybean/Full-Season Grain Sorghum*. April planted full-season grain sorghum, followed by wheat planted in October, then double-crop soybean planted in June after wheat harvest, then full-season grain sorghum planted the following April.
5. *Continuous Corn*. Corn planted in March or April every year.
6. *Continuous Soybean*. Early planted group 4 soybean planted in April every year.
7. *Full-Season Grain Sorghum/Early Planted Soybean.* Full-season grain sorghum planted in April, followed by April planted group 4 soybean planted the following year.
8. *Early Soybean/Wheat/Double-Crop Grain Sorghum/Soybean*. April planted group 4 soybean, followed by wheat planted in October, then double-crop grain sorghum planted in June after wheat harvest, followed by early planted group 4 soybean the following April.

The soil in the trial was a Memphis Silt Loam (Fine-silty, mixed, active, thermic Typic Hapludalf), which is a predominant soil type in the area. Crop rotation treatments were replicated 4 times within a randomized complete block design, and all rotation combinations were planted each year. Plot size was 25-ft wide (8 rows wide) by 200-ft long with a 38-in. row spacing. Before planting summer crops each year, plots were conventionally tilled, which included; disking, field cultivation, and bed formation by a roller-bedder so crops could be planted on a raised bed for furrow irrigation. Before planting wheat in October, plots that were going to be planted were disked, field cultivated, and rebedded. Wheat was then planted on raised beds with a grain drill with 6-in. row spacing with a seeding rate of 120 lb of seed/ac.

Soybean varieties planted changed throughout the trial. For April planted group 4 soybean, maturity ranged from 4.6 to 4.9 each year. Double-crop soybeans planted each year had a maturity range of 4.6 to 4.9. Corn hybrids varied by year and maturity ranged from 112 to 117 days. Full-season grain sorghum was Pioneer 84P80 from 2014-2018 and DKS51-01 in 2019. Double-crop grain sorghum hybrids grown included; Sorghum Partners 7715 and DKS 37-07, which are sugarcane aphid tolerant hybrids. In each year of the trial, Pioneer 26R41 soft red winter wheat was planted.

Summer crops were furrow irrigated as needed, according to the University of Arkansas System Division of Agriculture's Cooperative Extension Services' (CES) irrigation scheduler program. Normal production practices such as planting dates, seeding rates, weed control, insect control, and fertilizer recommendations for each crop followed current CES recommendations. Harvest yield data were collected from the center two rows of each plot at crop maturity, and remaining standing crops were harvested with a commercial combine. Soil nematode samples were collected at the trial initiation, and each subsequent fall after crop harvest and submitted to the University of Arkansas System Division of Agriculture's Nematode Diagnostic Lab at the Southwest Research and Extension Center at Hope, Arkansas. Soybean-cyst nematode was the only nematode that was found to be above economic thresholds levels during this trial, and levels were generally greater than 500 nematodes/100cm^3 of soil (data not shown). No root-knot nematodes were found in the trial area.

Results and Discussion

Soybean. April planted group 4 soybean yields were good each year with an average yield of 54–62 bu./ac depending on rotation over the 6 yr period (Table 1). The yield of April planted group 4 soybean was statistically impacted by the previous crop in 3 out of 6 years of the trial. Continuously grown soybean without rotation yielded 54 bu./ac on average, while soybean rotated with corn or full-season grain sorghum yielded 60 and 62 bu./ac, respectively (Table 1). Similar trends were noted with June planted double-crop soybean yields when following wheat. When double-crop soybean was following a previous crop of wheat/double-crop soybean, yields on average were only 40 bu./ac, while yields increased to 44 bu./ac when corn or full-season grain sorghum had been grown the previous year. However, double-crop soybean yields were only statistically influenced by the previous crop in 1 out of 6 years (Table 2). The yield differences of 60 bu./ac for early planted group 4 soybean following corn and 44 bu./ac for double-crop soybean following corn and wheat are similar to what many producers see on their farms between the early planted production system and the double-crop system. Differences in early planted and double-crop soybean yields between crop rotations can likely be attributed in part to lower soybean-cyst numbers following corn or grain sorghum each year (data not shown).

Corn. Corn yields were generally good over the 6 years and averaged 203–210 bu./ac depending on rotation (Table 3). Yields were statistically influenced by rotation in 1 out of 6 years with corn following corn yielding 26 bu./ac less than when following April planted group 4 soybean in 2016. Visually it was not apparent why there was a yield difference in 2016 as there were no notable differences in plant stands, foliar disease level, or late season lodging, and all inputs between rotations were constant. Over the 6-year period, corn following April planted group 4 soybean or June planted double-crop soybean yielded 6 or 7 bu./ac more, respectively, than continuously grown corn. These results are similar to other trials in which corn is grown in rotation with soybean, often yielding more than if grown without rotation (Sindelar et al., 2015). As corn is grown continuously for more years without rotation, yields may decline greater, but that trend is not evident after 6 years of this trial.

Wheat. Wheat yields were generally good, with an average yield of 65–72 bu./ac (Table 4), depending on rotation. Wheat yield was statistically influenced by previous crop 3 out of 5 years. When wheat was planted following full-season grain sorghum, yields were 7 bu./ac less on average than when following April planted group 4 soybean and 4 bu./ac less than when planted following June planted double-crop soybean or corn. The reason for lower wheat yields following full-season grain sorghum is not clear; however, fall and early winter growth was visibly reduced in some years. Grain sorghum has been reported to be possibly allelopathic to wheat under some circumstances. Although not definitive, allelopathy is suspected to have reduced wheat growth and yields in this study some years since all other management inputs such as tillage, seeding rate, fertilizer, foliar disease level, and plant stands were constant between treatments.

Grain Sorghum. Full-season grain sorghum was grown as a rotational crop and was always planted following soybean or double-crop soybean. Yields of full-season grain sorghum averaged 114 bu./ac and did not differ between the April planted group 4 soybean or double-crop soybean treatments over the 6-year period. State average grain sorghum yields generally range from 80–95 bu./ac. June planted double-crop grain sorghum following wheat averaged 87 bu./ac.

Practical Applications

Results from this on-going trial provide Arkansas producers with local non-biased information on how long-term crop rotation can impact yields of corn, early planted soybean, double-crop soybean, grain sorghum, double-crop grain sorghum, and wheat on their farms, which ultimately impacts the profitability of their farms.

Acknowledgments

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Table 1. Effect of previous crop on yield of April planted irrigated group IV soybean yield grown at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station, Marianna, Arkansas, 2014–2019.

	Soybean Grain Yield						
Previous Crop	2014	2015	2016	2017	2018	2019	Avg.
	(bu./ac)						
April Planted Soybean	43	49	47	65	56	62	54
Corn	64	49	52	71	67	58	60
Full-Season Grain Sorghum	64	51	56	74	64	62	62
Wheat/Double-Crop Sorghum	--	50	54	71	65	58	60
LSD (0.05)	13	NSD[a]	NSD	6	6	NSD	--

[a] NSD = No Significant Difference at α = 0.05.

Table 2. Effect of previous crop on yield of June planted irrigated double-crop soybean grown following wheat at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station, Marianna, Arkansas 2014–2019.

	Double-Crop Soybean Grain Yield						
Previous Crop	2014	2015	2016[a]	2017	2018	2019	Avg.
	(bu./ac)						
Double-Crop Soybean/Wheat	30	38	46	46	43	45	41
Corn/Wheat	39	43	49	48	46	47	45
Grain Sorghum/Wheat	40	42	50	48	46	46	45
LSD (0.05)	4	NSD[b]	NSD	NSD	NSD	NSD	--

[a] Wheat was not planted during the fall of 2015, but soybean were planted in June 2016 during the normal time for double-crop planting.

[b] NSD = No Significant Difference at α = 0.05.

Table 3. Effect of previous crop on yield of irrigated corn grown at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station, Marianna, Arkansas 2014–2019.

	Corn Grain Yield						
Previous Crop	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**Avg.**
	-----(bu./ac)-----						
April Planted Soybean	250	221	207	205	196	181	210
Wheat/Double-Crop Soybean	250	214	198	207	199	186	209
Corn	245	224	181	201	191	173	203
LSD (0.05)	NSD[a]	NSD	20	NSD	NSD	NSD	--

[a] NSD = No Significant Difference at α = 0.05.

Table 4. Effect of previous crop on yield of winter wheat grown at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station, Marianna, Arkansas 2014–2019.

	Wheat Grain Yield						
Previous Crop	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**Avg.**
	-----(bu./ac)-----						
April Planted Soybean	75	72	--	76	67	69	72
Double-Crop Soybean	75	69	--	73	64	64	69
Corn	72	68	--	74	69	61	69
Full- Season Grain Sorghum	69	73	--	56	62	65	65
LSD (0.05)	NSD[a]	4	--	12	6	NSD	--

[a] NSD = No Significant Difference at α = 0.05.

Table 5. Yield of irrigated full-season grain sorghum and double-crop grain sorghum grown at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station, Marianna, Arkansas 2014–2019.

	Grain Sorghum Grain Yield						
	2014	**2015**	**2016**	**2017**	**2018**	**2019**	**Avg.**
	-----(bu./ac)-----						
Full-Season Grain Sorghum	143	123	113	99	98	106	114
Double-Crop Sorghum	--	88	92	86	87	81	87

Genomic Regions Associated with Canopy Temperature in Soybean Under Drought

S.K. Bazzer[1] *and L.C. Purcell*[1]

Abstract

Soybean [*Glycine max* (L.) Merr.] production is often limited by drought stress. Canopy temperature (CT) under drought is a promising trait for identifying drought tolerance. During drought stress, decreased transpiration due to stomatal closure leads to increased CT. Therefore, CT can be used as an indicator of genotypes that can continue transpiration under drought conditions. Determining CT on a set of genotypes that differ in CT under drought allows the identification of quantitative trait loci (QTL) for CT that mark DNA regions on the chromosomes that confer cool CT. Our objective was to identify the genomic regions associated with CT from an aerial platform using an infrared camera attached to a drone. A population of 168 F_5-derived recombinant inbred lines (RILs) developed from KS4895 and Jackson were grown at the University of Arkansas System Division of Agriculture's Pine Tree Research Station near Colt, Ark. and the University of Arkansas System Division of Agriculture's Rohwer Research Station near Rohwer, Ark. for three consecutive years. Once the canopy was completely closed, CT measurements were made using a drone equipped with an infrared camera. Measured CT had a wide range in all environments, and there was a significant effect of genotype, environment, and the interaction between genotype and environment on CT. The QTL analysis identified 12 genomic loci present on nine chromosomes associated with CT that individually explaining 5.3–12.3% of the CT variation. The identified QTLs coincided with genomic regions associated with drought tolerance-related traits found in previous studies. Identified QTLs may be valuable in improving drought tolerance in soybean.

Introduction

Soybean is one of the most important crops grown in the U.S., and the U.S. contributes around 34% to world soybean production (http://soystats.com/). In the U.S., drought stress leads to a reduction of 5–60% of soybean production every year. Thus, there is a need for the development of cultivars with drought tolerance to cope with adverse climatic conditions. As early as 1981, canopy temperature (CT) was proposed as an important physiological trait associated with drought tolerance (Jackson et al. 1981). The decrease in both transpiration and stomatal conductance under water deficit conditions limits evaporative cooling, which leads to increased CT (Jones et al., 2010). Genotypes with a cooler canopy under water deficit conditions may have more soil available water or have greater stress tolerance than those genotypes with higher CT. Various studies have reported a significant correlation between cooler CT and high yield (Fischer et al., 1998; Lopes and Reynolds, 2010). Bai and Purcell (2018) found that slow wilting genotypes had cooler canopy than fast wilting genotypes, and a cooler canopy was positively associated with grain yield in soybean.

Manual phenotyping of transpiration rate and stomatal conductance to detect CT differences is difficult and tedious. The advent of high throughput phenotyping platforms such as unmanned aerial systems (UAS) leads to rapid, accurate, and non-destructive monitoring of a large number of experimental fields for quantitative assessment of CT in segregating mapping populations and allowing a comparison among genotypes for CT differences (Jones et al., 2009). Thermal infrared imaging for CT combined with genetic mapping provides a powerful tool in identifying genomic regions associated with drought tolerance. Therefore, this present study aimed to identify the genomic regions associated with CT using a mapping population of 168 F_5- derived recombinant inbred lines (RILs) developed from a cross of KS4895 × Jackson.

Procedures

The field experiments were conducted at the Pine Tree Research Station, near Colt, Ark. and Rohwer Research Station, Rohwer, Ark. for three consecutive years (2017–2019). Plots consisted of 7 drilled rows, spaced 7.5-in. apart that were 14-ft in length. The experimental design at each location was a randomized complete block with 2 replications. Once the canopy was completely closed, a DJI Phantom 4 drone (Dji.com) equipped with a FLIR Tau 2 infrared camera (flir.com) was flown at 400-ft above the ground to make CT measure-

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ments. The camera had a resolution of 640 × 512 pixels and a lens with a 25-mm focal length. A digital video recorder was attached to the infrared camera, and individual frames from the video stream were selected and processed using Field Analyzer (www.turfanalyzer.com) software to extract infrared intensity (IR) values as a measure of CT. Data from IR images included greyscale values ranging from 0 to 255 with a sensitivity of 0.09 °F, with a range of approximately 22.5 °F (256 × 0.09 °F). The CT readings were taken on clear days between 1200 and 1430 h. There were mild drought stress conditions at the time of measurements for all environments except for Pine Tree in 2017.

The analysis of IR values was performed using SAS version 9.2 (SAS Institute Inc, Cary, N.C.). Descriptive statistics and analysis of variance (ANOVA) were performed by using the PROC UNIVARIATE and PROC MIXED procedures, respectively. Each location by year combination was treated as an individual environment. The genetic map of the 08705 population previously constructed by Hwang et al. (2015) was used for QTL analysis. There were 511 single nucleotide polymorphic (SNP) markers plus an additional 37 simple sequence repeat (SSR) markers used to create the genetic map with an average of 3.8 centimorgans between markers (Hwang et al., 2015). The QTL analysis was performed by using WinQTL Cartographer v.2.5 using composite interval mapping (CIM) (Wang et al., 2007).

Results and Discussion

Infrared intensity values had a wide range in all environments, and it was found that the parent Jackson had a cooler canopy relative to KS4895 in all environments (Table 1). The ANOVA indicated a significant effect ($P < 0.05$) of RILs, environment, and the interaction between RILs and the environment on CT, indicating that CT among genotypes responded differently in different environmental conditions. The low heritability ($h^2 = 31\%$) of this trait also indicates that the environment plays a significant role in CT. The QTL analysis identified 12 genomic loci on nine chromosomes associated with CT in different environments (Fig. 1). The identified genomic loci individually explained 5.3%–12.3% of the phenotypic variation.

We did not find any genomic regions associated with CT at Pine Tree in 2017, presumably because drought stress was minimal during the measurement period. In general, there was inconsistent detection of genomic loci controlling the variation in CT in different environments. That is, QTLs associated with CT tended to be unique for each environment. Fig. 1 shows the position of 12 QTLs associated with CT on the 20 soybean chromosomes as red horizontal bars. The position of QTLs reported from previous experiments (Hwang et al., 2015; Kaler et al., 2018) for canopy wilting, CT, water use efficiency, and root morphology traits are also shown in Fig. 1 and align closely to the positions for CT, which provides support that CT QTLs are important in conferring drought tolerance.

Practical Applications

This is the first study in soybean that identified the genomic regions associated with CT using a population derived from two parents. This research lays the foundation for the integration of IR thermography with genetic studies to accelerate the drought tolerance improvement in soybean breeding programs. Research in this area will lead to the fine mapping of these loci for their use in marker-assisted selection and improving soybean drought tolerance.

Acknowledgments

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Table 1. Phenotypic variations for canopy temperature (CT) [represented as infrared (IR) values] in the parents (KS4895 and Jackson) and recombinant inbred lines (RIL) population evaluated at the University of Arkansas System Division of Agriculture's Pine Tree Research Station [in 2017 (PT17), 2018 (PT18), and 2019 (PT19)] and at the Rohwer Research Station [in 2017 (RH17), 2018 (RH18) and 2019 (RH19)].

	PT17	RH17	PT18	RH18	PT19	RH19
KS4895	70.33	66.94	71.05	58.64	67.95	85.16
Jackson	58.75	56.56	54.13	46.69	60.55	53.67
Mean	63.19	59.76	58.06	50.15	63.70	64.60
Standard deviation	8.43	5.08	6.95	4.51	7.59	6.29
Range	45.17	28.80	36.70	23.99	45.49	35.65
Skewness	0.63	0.72	1.00	0.85	0.44	-0.33
Kurtosis	0.60	0.69	1.29	0.55	0.30	0.23

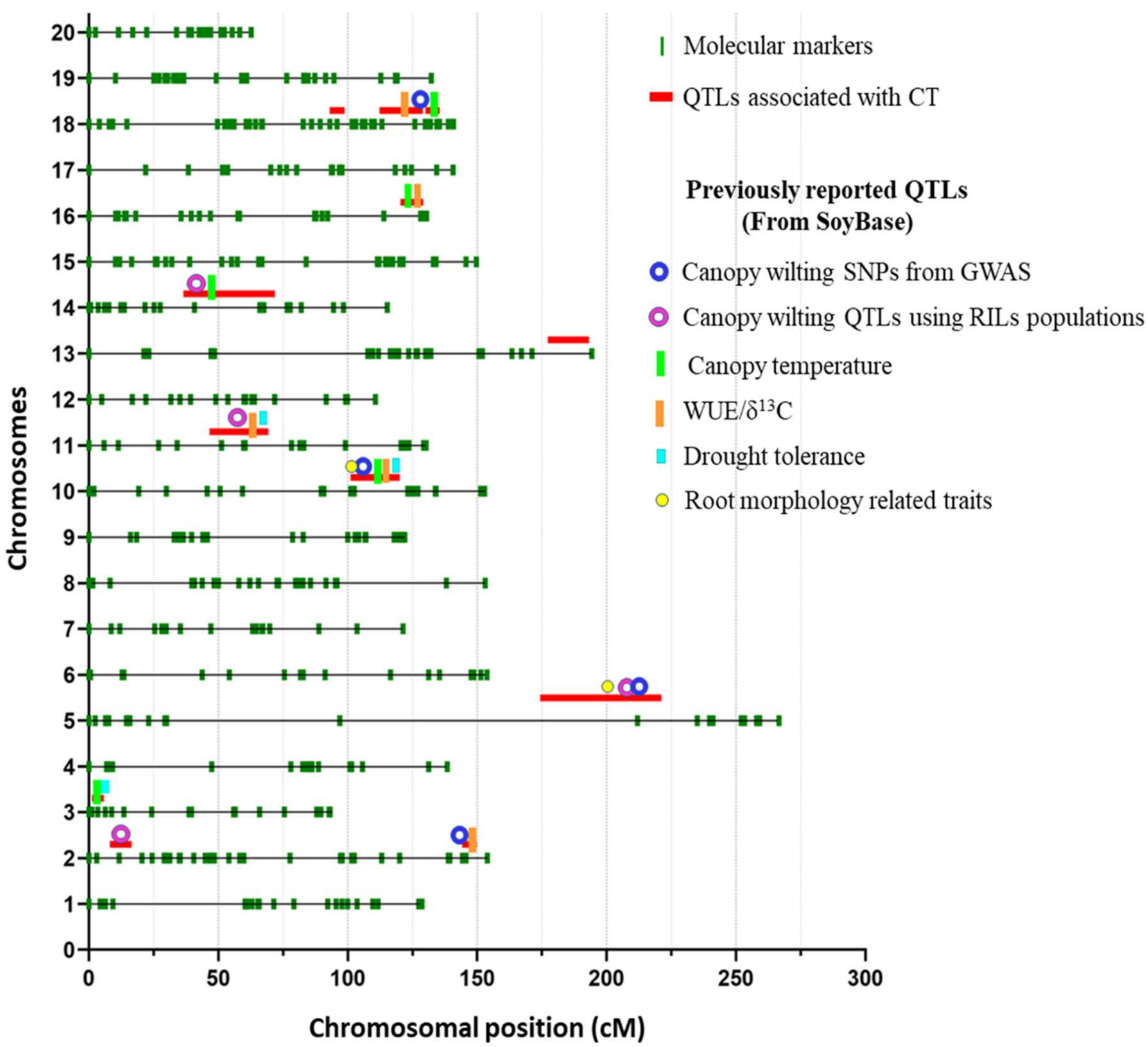

Fig. 1. Position of quantitative trait loci (QTLs) (horizontal red bars) on soybean chromosomes associated with canopy temperature (CT) identified in KS4895 × Jackson recombinant inbred lines (RIL) population in individual environments. Vertical colored bars and symbols indicate the QTLs associated with canopy wilting, CT, water use efficiency (WUE), and root morphology found at the same positions in previous studies (soybase.org).

Soybean Genomic Regions Associated with Water Use Efficiency as Determined by Carbon Isotope Ratio ($\delta^{13}C$)

S.K. Bazzer[1] and L.C. Purcell[1]

Abstract

Soybean [*Glycine max* (L.) Merr.] is often limited by drought stress during the growing season. One metric for improving drought tolerance is an improvement in crop water use efficiency (WUE). Water use efficiency characterizes the amount of plant mass that the crop can accumulate for each unit of water lost through transpiration. Water use efficiency is closely associated with the ratio ($\delta^{13}C$) of the heavy, non-radioactive isotope of carbon (^{13}C) relative to the more abundant ^{12}C isotope, and $\delta^{13}C$ has been used as a proxy for WUE in several crops. Our objective was to identify the genomic regions, or quantitative trait loci (QTLs), associated with $\delta^{13}C$ using two different biparental populations that were phenotyped in multiple environments. The $\delta^{13}C$ ratio had a wide phenotypic range in all environments in both populations with high heritability. Further QTL analysis identified nine genomic loci on seven chromosomes associated with $\delta^{13}C$ in one population and eight loci on seven chromosomes associated with $\delta^{13}C$ in the second population. Loci associated with $\delta^{13}C$ were present on chromosome 20 for both populations. Several of the identified $\delta^{13}C$ QTLs overlapped with QTLs identified in other research for drought tolerance-related traits. The $\delta^{13}C$ QTLs may be important resources in soybean breeding programs to improve drought tolerance.

Introduction

Soybean is one of the most important row crops grown in the U.S., and Arkansas is the 8th largest producer of soybean in the country. A primary production constraint is drought stress, which leads to a 5–60% decrease in yield every year. The development of cultivars with drought tolerance may help to improve crop performance under these adverse climatic conditions.

Water use efficiency (WUE) is an important physiological trait for improving crop productivity in water-limited conditions. However, phenotyping for WUE is difficult, laborious, and expensive under field conditions. The ratio of the heavier carbon isotope ^{13}C to the more abundant ^{12}C isotope in plant tissues ($\delta^{13}C$) is positively correlated with WUE and has been used as a proxy for WUE in several crops (Dhanapal et al., 2015; Kaler et al., 2017; Richards et al., 1999). Importantly, $\delta^{13}C$ has high heritability and is not impacted greatly by the environment.

The integration of conventional breeding techniques with modern molecular tools for improving WUE may help to increase soybean resilience to water deficit conditions. Quantitative trait loci (QTLs) analysis can dissect and characterize the genetic complexity of $\delta^{13}C$ and lead to a better understanding of the genetic architecture of $\delta^{13}C$. Several QTLs associated with $\delta^{13}C$ have been identified in soybean (Bazzer et al., 2020; Dhanapal et al., 2015; Kaler et al., 2017) and various other crops (Peleg et al., 2009; Xu et al., 2009; Teulat et al., 2002).

Therefore, the objective of the present study was to map novel genomic regions associated with $\delta^{13}C$ from two different biparental, recombinant inbred populations. The information from this study will help understand the genetic control of $\delta^{13}C$ and tag the genes responsible for $\delta^{13}C$ and WUE. Correlating this genetic information with other physiological and morphological traits related to drought tolerance will allow the development of soybean varieties with high WUE and improved drought tolerance.

Procedures

Two recombinant inbred line (RIL) populations were evaluated in this research. The first population, '08705 population,' consisted of 168 F_5-derived RILs from a cross of KS4895 (drought-sensitive) and Jackson (drought tolerant) [TLR2] genotypes. The second biparental population, the 'PI population,' consisted of 196 F_6-derived RILs derived from a cross between PI 416997 (high WUE) and PI 567201D (low WUE).

The 08705 population field experiments were conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Ark. in 2012 (ST12) and 2013 (ST13), and at the Northeast Research and Extension Center in Keiser, Ark. in 2013 (KS13) under

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rainfed (RF) and irrigated (IRR) conditions. Similar experiments were conducted at the Pine Tree Research Station near Colt, Ark. (PT17) and the Rohwer Research Station near Rohwer, Ark. (RH17) in 2017 under RF conditions. Each plot consisted of 2 rows, spaced 30–38 in. apart and 15–17-ft long at Stuttgart and Keiser. At PT17 and RH17, plots consisted of nine rows spaced 7.5 in. apart that were 14-ft in length. The PI population was grown at Stoneville, Miss. in 2016 (ST16) and 2017 (ST17), Columbia, Mo. in 2017 (CO17), and at the University of Arkansas System Division of Agriculture's Milo J. Shult Agricultural Research and Extension Center in Fayetteville, Ark. in 2017 (FAY17). For both years at Stoneville, plots consisted of one row, 26 in. apart and 9-ft in length. At Columbia, single row plots were 10-ft long and spaced 30 in. apart. At Fayetteville, plots consisted of 2 rows, 20-ft in length with 18 in. between rows. The field experiments of both populations were arranged as a randomized complete block design with two replications and were managed using recommended agricultural practices.

For isotope analysis, between begin bloom (R1) and full bloom (R2) growth stages, the aboveground portion of four random plants from each plot was harvested. The harvested plant samples were dried at 60 °C and coarse and then finely ground to pass a 6- and 1-mm sieve, respectively. A subsample (500 mg) of finely ground samples was placed in a 15-mL tube with two 9.52-mm stainless steel balls and ground to a fine powder for 10 min at 1500 rpm using a Geno Grinder (SPEX CertiPrep, Inc., N.J.). Thereafter, approximately 3–5 mg of the finely powdered samples were placed in tin capsules and submitted to U.C. Davis Stable Isotope Facility (http://stableisotopefacility.ucdavis.edu/) for isotope analysis. Data from the stable isotope facility were received as $\delta^{13}C$ (‰) and were expressed relative to the international standard of the $^{13}C/^{12}C$ ratio Vienna PeeDee Belemnite (V-PDB) as:

$$\delta^{13}\,C = \frac{R_{sample}}{(R_{std} - 1)} * 1000$$

where, R_{sample} and R_{std} are the isotope ratios of the sample and standard, respectively.

For statistical analysis of $\delta^{13}C$, the combinations of location and year were considered as an individual environment. Descriptive statistics and Pearson correlation analysis were calculated using PROC UNIVARIATE and PROC CORR procedures (α = 0.05) of SAS version 9.4 (SAS, Institute, 2013), respectively. The PROC MIXED (α = 0.05) procedure of SAS 9.4 was used for the analysis of variance (ANOVA) to determine the effects of genotype, environment, and genotype × environment interactions on $\delta^{13}C$. The genetic map of the 08705 population was previously constructed by Hwang et al. (2015) using 548 polymorphic markers and was used for QTL analysis with WinQTL Cartographer version 2.5 software. Similarly, the genetic map of the PI population was constructed with 2466 polymorphic single nucleotide polymorphism markers (SNPs) having a total map length of 3836 centi-morgans (cM). The QTL analysis for the PI population was performed using IciMapping v. 4.1 software (http://www.isbreeding.net/), which allowed the identification of QTLs, QTL × QTL interactions, and QTL × environment interactions.

Results and Discussion

08705 Population. The field experiments for the 08705 population were conducted in five environments (ST12, ST13, KS13, PT17, and RH17) to evaluate $\delta^{13}C$ under RF and IRR conditions. There were large variations in $\delta^{13}C$ under RF and IRR conditions within environments (Table 1), and $\delta^{13}C$ values under RF conditions were greater than IRR conditions within all environments, indicating greater WUE under water deficit conditions. There was a significant positive correlation ($P \leq 0.01$) of $\delta^{13}C$ of RILs between all environments and irrigation conditions ($0.27 \leq r \leq 0.65$) except for ST12_RF and PT17_RF in which the correlation was not significant (data are not shown). Analysis of variance showed significant effects of genotype (G), environment (E), and G × E interactions, whereas irrigation effect within the environment and its interaction with G was non-significant (data not shown). Narrow sense heritability of $\delta^{13}C$ over environments and over irrigation treatments was 83%. The QTL analysis identified a total of 24 QTLs associated with $\delta^{13}C$. When considering the overlapping confidence intervals, these 24 QTLs were clustered in nine genomic loci on seven chromosomes (Fig. 1). The QTL clusters on chromosomes Gm05 (1), Gm06 (2), and Gm20 (1) were detected across different environments and irrigation regimes. Collectively, these four QTL clusters accounted for 55% of the phenotypic variation in $\delta^{13}C$. The QTLs on chromosomes Gm06 and Gm20 also showed QTL × QTL interaction that contributed approximately 4.2% to the total phenotypic variation (data not shown).

Similarly, there was a wide phenotypic variation of $\delta^{13}C$ in the PI population (Table 2). PI 416997 (high WUE) had consistently greater $\delta^{13}C$ values than PI 567201D (low WUE), which is consistent with previous research (Kaler et al., 2017). There were significant positive correlations ($0.67 \leq r \leq 0.78$) between different environments for $\delta^{13}C$, indicating the stability of $\delta^{13}C$ across environments (data not shown). Analysis of variance of $\delta^{13}C$ showed significant ($P \leq 0.001$) effects of G, E, and G × E interactions on $\delta^{13}C$ (data not shown). Narrow sense heritability was 90% across environments, indicating that selection based $\delta^{13}C$ could be effective in improving WUE in soybean.

The QTL analysis identified 16 QTLs on seven chromosomes in the four environments that individually explained 2.5–29.9% of the phenotypic variation (data not shown). Based on their overlapping confidence intervals, these 16 QTLs constituted eight loci on seven chromosomes (Fig. 2). Two loci on chromosome Gm20 were detected in at least three environments and were considered as stable loci. The favorable allele that increased δ13C for these loci were from both parents. Six QTLs showed significant QTL × E, and there were QTL × QTL interactions between different genomic regions and QTLs present on Gm20 (data not shown). The identification of additive QTLs, QTL × environment interactions and QTL × QTL interactions indicates the complex nature of $\delta^{13}C$.

The nearest marker linked with these loci associated with $\delta^{13}C$ in both populations are candidates for marker-assisted selection in future breeding efforts to improve WUE. It was also found that $\delta^{13}C$ loci in both populations overlapped with genomic regions associated with $\delta^{13}C$, canopy wilting, drought index, hydraulic conductance, and other physiological traits that were identified in previous drought-related studies. In addition, QTLs present on chromosome Gm20 were identified in both populations. Identified genomic regions may be important resources in soybean breeding programs to improve tolerance to drought.

Practical Applications

This research identified genomic regions associated with carbon isotope ratio ($\delta^{13}C$) under different environments in different populations, and these genomic regions could be targets to improve WUE using marker-assisted selection. The findings from this study provide useful information on the genetic basis of WUE and may be helpful in the genetic improvement of yield potential in drought-prone environments.

Acknowledgments

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Table 1. Descriptive statistics of δ[13]C (‰) for the 08705 population, derived from a cross between KS4895 and Jackson. The population was evaluated at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center in Keiser in 2013 (KS13), the Rice Research and Extension Center near Stuttgart in 2012 and 2013 (ST12 and ST13) under rainfed (RF) and irrigated (IRR) conditions, and at the Pine Tree Research Station near Colt (PT17) and the Rohwer Research Station near Rohwer (RH17) in 2017 under RF conditions.

Descriptive statistics	KS13_RF	KS13_IRR	ST12_RF	ST12_IRR	ST13_RF	ST13_IRR	PT17_RF	RH17_IRR
KS4895	-28.40	-28.46	-28.45	-28.74	-28.45	-28.38	-27.87	-27.88
Jackson	-29.02	-28.95	-28.62	-28.57	-29.00	-29.24	-28.42	-28.13
Parents mean	-28.71	28.71	-28.54	-28.65	-28.73	-28.81	-28.15	-28.00
Population mean	-28.13	-28.28	-28.49	-28.59	-28.68	-28.87	-27.87	-28.18
Range	1.64	1.68	1.97	2.34	1.69	1.97	2.15	1.60
Standard deviation	0.30	0.33	0.37	0.36	0.31	0.35	0.37	0.32
Variance	0.09	0.11	0.14	0.13	0.09	0.12	0.14	0.10
Kurtosis	0.18	-0.27	-0.05	0.10	0.05	0.25	-0.15	0.02
Coefficient of variation (%)[a]	1.05	1.15	1.31	1.26	1.08	1.20	1.33	1.13

[a] Absolute value of coefficient of variation.

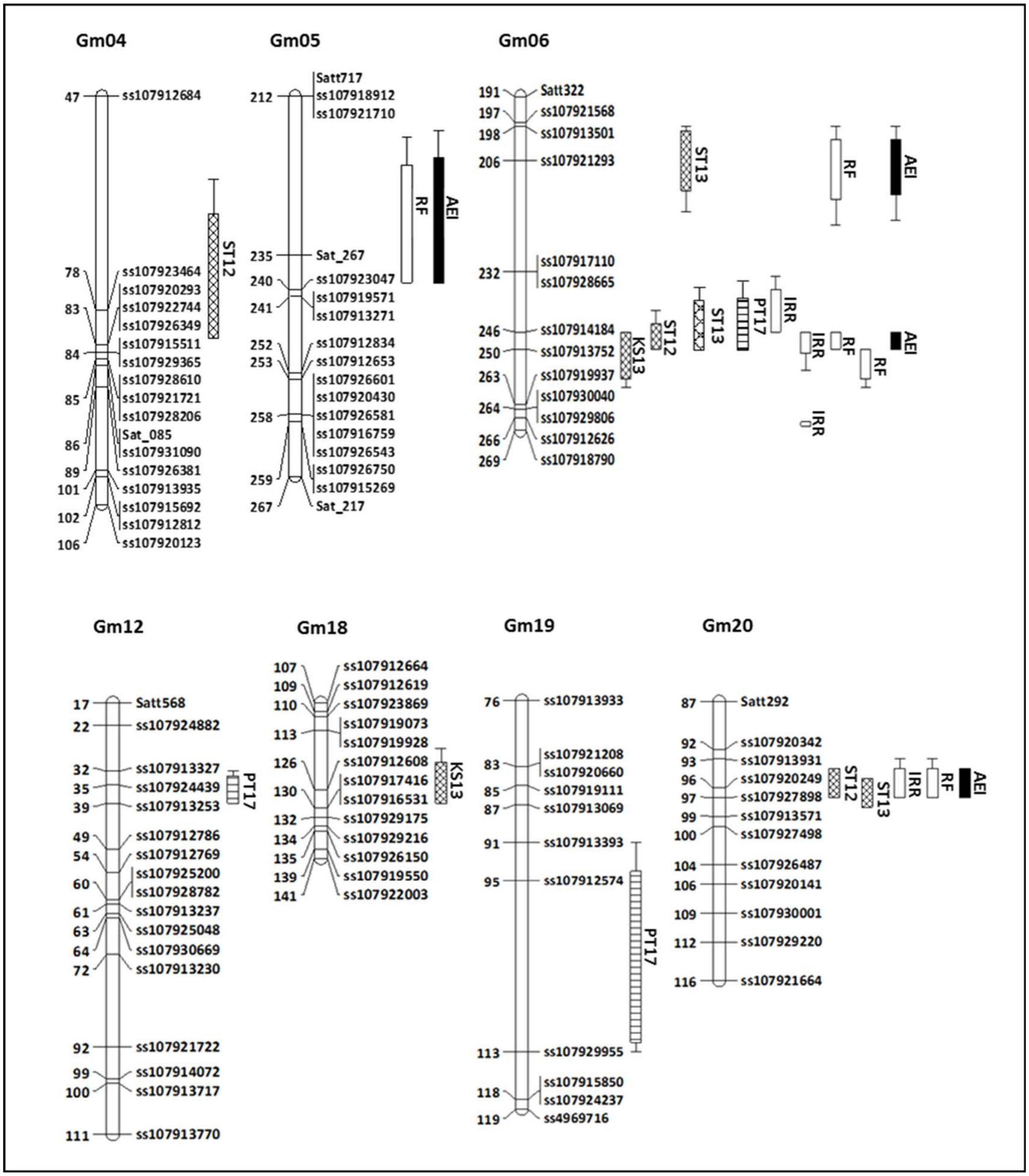

Fig. 1. Position of quantitative trait loci (QTLs) associated with $\delta^{13}C$ based on composite interval mapping (CIM) in the 08705 population. The cross-hatched bar indicates the QTLs identified in different environments (the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center at Keiser in 2013 (KS13), the Rice Research and Extension Center near Stuttgart in 2012 and 2013 (ST12, ST13), the open bar indicates the QTLs were identified in different irrigation conditions (RF = Rainfed and IRR = Irrigated), and the solid bar indicates the QTLs were identified when averaged over environments and irrigation conditions (AEI). Bars with horizontal lines indicate the QTLs were identified in the Pine Tree Research Station, near Colt, environment in 2017 (PT17) under RF conditions.

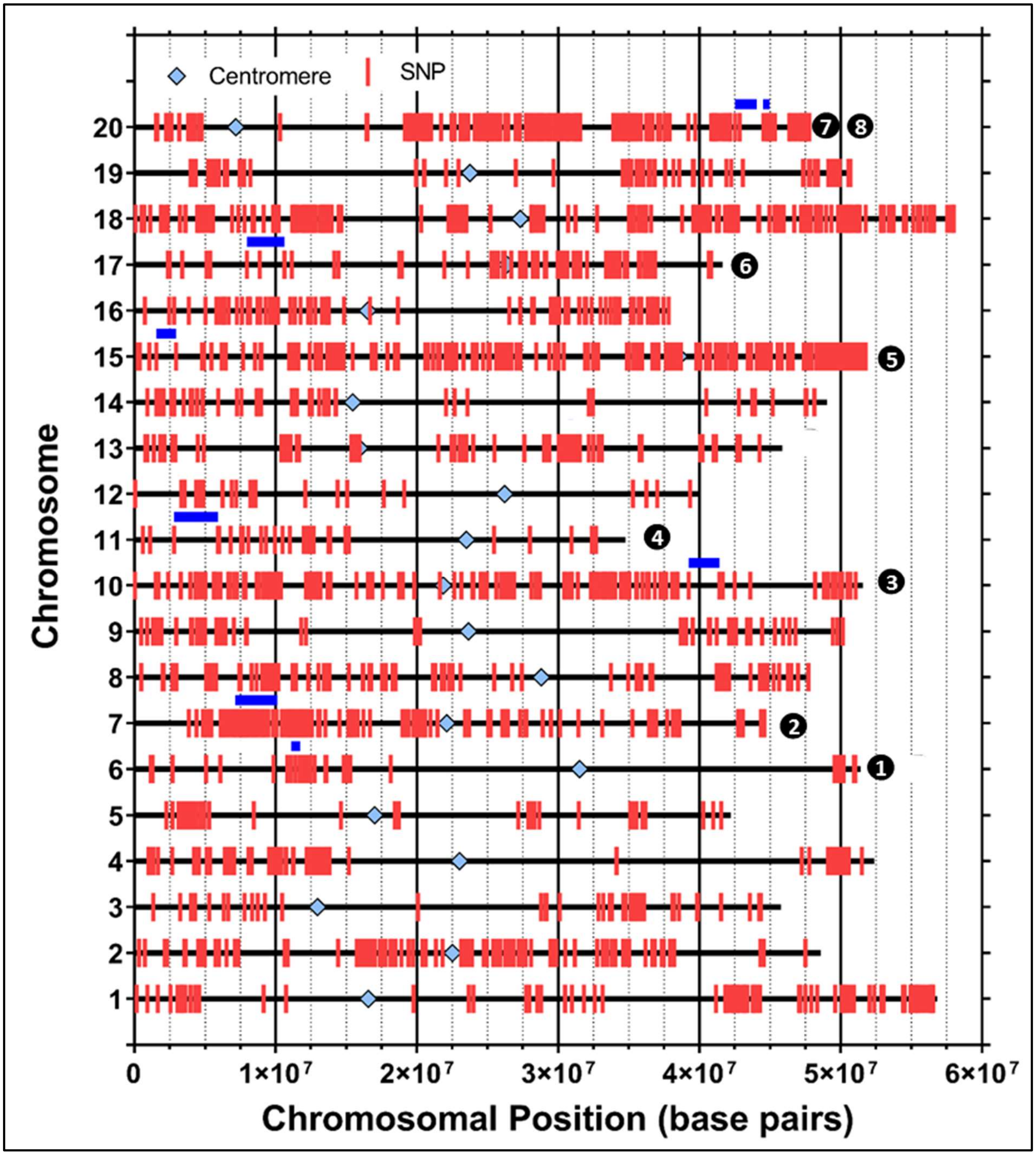

Fig. 2. The physical position of single nucleotide polymorphism markers (SNPs) on soybean chromosomes and position of loci associated with δ^{13}C identified by IciM mapping software. The physical positions of SNP markers indicated in base pairs are shown on the x-axis, and the y-axis represents chromosome number. The solid blue diamond represents the centromere location. The numbers in the black circles represent the locus numbers on a specific chromosome. The QTL positions for individual loci are designated by a blue bar above the respective chromosome.

Table 2. Descriptive statistics of $\delta^{13}C$ (‰) for the PI population, derived from a cross between PI 416997 and PI 567201D. The population was evaluated at Stoneville, Miss. in 2016 (ST16) and in 2017 (ST17), Columbia, Mo. in 2017 (CO17), and at the University of Arkansas System Division of Agriculture's Milo J. Shult Agricultural Research and Extension Center in Fayetteville, Ark. in 2017 (FAY17).

Descriptive statistics	ST16	ST17	CO17	FAY17
PI 416997	-29.24	-28.39	-27.81	-27.94
PI 567201D	-30.08	-30.47	-28.75	-27.99
Population mean	-29.61	-29.22	-28.32	-28.40
Range	2.38	2.44	2.36	2.85
Standard deviation	0.42	0.44	0.42	0.63
Variance	0.17	0.19	0.18	0.40
Skewness	0.20	0.97	1.06	1.18
Kurtosis	1.31	1.21	1.04	0.73
Coefficient of variation (%) [a]	1.41	1.51	1.49	2.43

[a] Absolute value of coefficient of variation.

Identification of Genomic Regions Associated with Yield in Soybean

S.K. Bazzer,[1] A.S. Kaler,[1] C.A. King,[1] and L.C. Purcell[1]

Abstract

Soybean [*Glycine max* (L.) Merr.] varieties with higher yield potential and greater yield stability are needed to meet the requirements of our expanding population and more drought-prone climate. The objective of this study was to identify genomic regions associated with yield under drought conditions using a population of recombinant inbred lines derived from a cross between KS4895 and Jackson. The experiment was conducted in 2017 at the University of Arkansas System Division of Agriculture's Pine Tree (near Colt, Ark.) and Rohwer (near Rohwer, Ark.) Research Stations. Drought stress at both locations was minimal, and the yield was relatively high. Analysis of variance (ANOVA) showed significant effects of genotype, environment, and genotype × environment interactions. Averaged values of yield across environments identified two genomic regions associated with yield on chromosomes Gm11 and Gm12, which collectively accounted for 37% of the phenotypic variation with individual R^2 values of 0.07 and 0.30, respectively. Within single environments, four genomic regions were identified on chromosomes Gm04 and Gm11 (R^2 values ranging from 0.07 to 0.40). The favorable allele for all these genomic regions was from Jackson. Identified genomic regions were also found to be associated with the slow-wilting trait based upon previous studies. These identified genomic regions may serve as an important resource in soybean breeding to improve yield potential and yield stability across environments.

Introduction

The world's population is expected to increase to approximately 9 billion by 2050, and food production needs to increase by 70% by 2050 to meet the demand of the world's growing population. One of the solutions to achieve the projected production demand is by integrating conventional breeding techniques with modern molecular tools for soybean improvement (Collard et al., 2008). Information on the number and chromosomal locations of the genetic loci influencing the expression of a trait, their relative contribution to the trait expression, and their sensitivity to variations in different environments are important for the utilization of these loci for crop improvement (Marathi et al., 2012). Genetic loci (Quantitative trait loci/QTLs) analysis can dissect and characterize the genetic complexity of yield traits and lead to a better understanding of the genetic architecture of yield (Zhang et al., 2016).

Therefore, the objective of the present study was to map novel genomic regions influencing yield using multi-location phenotyping data from a population of recombinant inbred lines (RILs) generated by crossing between KS4895, a high-yielding line, and Jackson, a genotype with drought-tolerant N_2 fixation (Purcell, 2009). Soybean yield is affected by drought stress at almost all stages of growth; and, N_2 fixation is particularly sensitive to drought that leads to yield reduction (Purcell, 2009; Purcell et al., 2004). Therefore, breeding for improved N_2 fixation under drought is critical for increasing soybean resilience to drought (Purcell, 2009).

This research will help us understand the genetic control of yield and its components under various environmental conditions. Correlating this genetic information with other physiological and morphological traits related to drought tolerance will allow the development of soybean varieties with high yield and tolerance to drought stress.

Procedures

A population of 168 RILs derived from a cross between KS4895 × Jackson, were used to identify the QTLs associated with yield. The experiment was conducted at the University of Arkansas System Division of Agriculture's Pine Tree Research Station near Colt, Ark. (35°7'N, 90°55'W) on a Calloway silt loam (PT2017) and at Rohwer Research Station near Rohwer, Ark. (33°48'N, 91°17'W) on a Sharkey silty clay (RH2017) in 2017. At Pine Tree, plots consisted of 9 rows spaced 7 in. apart that were 14-ft in length, whereas at Rohwer, there were 9-row plots with 6-in. spacing that were 13-ft in length. The experimental design at each location was a randomized complete block design with two replications.

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Yield data were collected from both environments at harvest maturity and corrected to 13% moisture. The experiment was rainfed at both locations, but drought stress was minimal due to frequent and timely rainfall events.

Descriptive statistics of yield data for each environment were calculated using PROC UNIVARIATE of SAS version 9.4 (SAS, Institute, Cary, N.C. 2013). The PROC MIXED (α = 0.05) procedure of SAS 9.4 was used for analysis of variance to determine the effects of genotype (G), environment (E), and G × E interactions on yield. Genotype and E were treated as fixed effects, and replication within the environment was considered as a random effect. Pearson's correlation coefficients (r) were calculated using PROC CORR in SAS 9.4 to determine the consistency of yield data between individual environments (PT2017 and RH2017). Broad-sense heritability estimates (H) of yield on a genotypic mean basis were calculated for combined data across all environments using the variance components obtained from an analysis of variance. For genetic mapping, linkage map of the population was constructed using 548 polymorphic markers. The entire genetic map was scanned for QTLs by composite interval mapping with a walking speed of 1 cM using WinQTL Cartographer (Wang et al., 2010). A critical LOD (log of odds) for declaring the presence of putative QTL was determined by permutation tests based on 1000 iterations.

Results and Discussion

There was a broad range of yield within each environment, indicating wide phenotypic variation, and yield data were normally distributed within each environment. Yields were relatively high and ranged from 33–77 bu./ac at Pine Tree and from 17–61 bu./ac at Rohwer (Table 1). There were significant ($P \leq 0.05$) G, E, and G × E interaction effects on yield (Table 2). Yield between the two environments was significantly correlated but was low (r = 0.22). Broad sense heritability of yield on an entry-mean basis was 48%.

Using molecular marker information, we identified two genomic regions (or QTLs) associated with averaged values of yield across environments. One genomic region/QTL was on chromosome Gm11 (LOD = 12.95), and one was on Gm12 (LOD = 3.41), which collectively accounted for 37% of the phenotypic variation with individual R^2 values of 0.30 and 0.07, respectively. Within single environments, we identified four genomic regions/QTLs: one QTL on chromosome Gm04 from Pine Tree (R^2 = 0.10) and three QTLs on chromosome Gm11 from Rohwer (R^2 values ranging from 0.07 to 0.40). The number, genomic locations, and effects of genomic region/QTL associated with yield are summarized in Table 3. In all cases, the increased yield was from the Jackson allele. The three QTLs on chromosome Gm11 correspond to the same general positions that we found previously associated with slow wilting (Hwang et al., 2015). The QTLs on chromosomes Gm04 and Gm12 were also close to genomic regions associated with canopy wilting identified in multiple soybean mapping populations (Hwang et al., 2015). It is possible that the slow-wilting allele at these positions may be responsible for increasing yield under drought conditions.

Practical Applications

This experiment identified genomic regions associated yield under different environments, and these genomic regions could be targets to improve yield under stress and non-stress conditions using marker-assisted selection. Stable genomic regions identified across locations provide an excellent opportunity for selecting breeding lines that contribute to higher yield potential. Research in this area will lead to the fine mapping of these loci for their use in marker-assisted selection.

Acknowledgments

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Table 1. Descriptive statistics of yield from a soybean trial at the University of Arkansas System Division of Agriculture's Pine Tree and Rohwer Research Stations in 2017.

Descriptive Statistic	Pine Tree	Rohwer
	----------------bu./ac----------------	
Minimum	32.9	16.5
Maximum	77.2	61.1
Range	44.3	44.6
Mean	57.7	40.4
Median	58.4	40.5
Standard Deviation	7.3	9.2
Coeff. Variation (%)	12.7	22.9
Skewness	-0.43	0.03
Kurtosis	0.45	-0.50

Table 2. Analysis of variance of yield for experiments conducted at the University of Arkansas System Division of Agriculture's Pine Tree and Rohwer Research Stations in 2017.

Source of variation	DF[a]	F-value	Pr > F
Genotype (G)	167	4.31	<0.0001
Environment (E)	1	295.5	0.0034
G × E	167	2.22	<0.0001

[a]DF = Degrees of freedom.

Table 3. Yield associated genomic regions identified in experiments in 2017 at the University of Arkansas System Division of Agriculture's Pine Tree (PT2017) and Rohwer Research Stations (RH2017) or averaged across environments (AE).

Environment	Chromosome	Position	Nearest Marker	LOD	Favorable allele	R^2
		(cM)				
AE	Gm_11	55.3	BARC-032817-09052 (s19087)	12.95	Jackson	0.30
	Gm_12	97.3	BARC-049209-10821 (s21722)	3.41	Jackson	0.07
PT2017	Gm_04	82.6	BARC-058213-15160 (s26349)	4.41	Jackson	0.10
RH2017	Gm_11	54.3	BARC-032817-09052 (s19087)	14.2	Jackson	0.31
	Gm_11	64.4	BARC-040309-07711 (s13812)	14.6	Jackson	0.40
	Gm_11	89.1	BARC-059773-16088 (s27357)	2.6	Jackson	0.07

Assessment of Soybean Varieties in Arkansas for Sensitivity to Chloride Injury

V.S. Green[1] *and M. Conatser*[2]

Abstract

Chloride is essential for plant growth and function but can be excessively available in soil and irrigation water. Soybean [*Glycine max* (L.) Merr.] has been recognized as a chloride sensitive crop with certain lines or varieties being much more prone to tissue damage and seed yield reduction than others. The propensity to chloride injury is controlled by a genetic trait expressing sensitivity or tolerance. Vegetatively grown soybean varieties were exposed to elevated chloride salt concentrations while in a controlled environment. Leaf tissue was collected and analyzed for chloride content and compared to known tolerant and sensitive varieties. An injury-potential assessment was made for each variety based on relative leaf tissue chloride concentrations. During 3 years of assessment, from 2017 through 2019, 31% of maturity group 4 (MG 4) soybean varieties screened expressed chloride tolerance. For maturity group 5 (MG 5) soybean varieties, 42% expressed chloride tolerance. Identifying varietal chloride tolerance allows for the maximization of seed yield for soybean grown on soils with elevated chloride content.

Introduction

Soybean represents the largest cash crop grown in Arkansas. Flexibility makes soybean an integral option in the state. Popular crop rotations, such as rice (*Oryza sativa*)-soybean or corn (*Zea mays*)-soybean, encourage soil health benefits. As with many commodities, profit margins are tight, and productivity must remain high. Factors that limit crop yield must be identified and corrected when possible. Harmful levels of chloride salts have become an identifiable limiting factor to soybean yield in Arkansas.

Elevated concentrations of chloride salts can be found in natural soil horizons but are more commonly noted with the application of irrigation water from wells pumping high levels of chloride. Many field crops can be damaged by high chloride levels (Shannon, 1997), but soybean has specifically been noted as being acutely sensitive to chloride salts (Rupe et al., 2000). Some soybean varieties exhibit a genetic propensity for the exclusion of harmful chloride from their leaves and stems, where excessive accumulation can cause tissue damage and subsequent seed yield loss (Abel, 1969). Sensitive varieties may experience leaf tissue damage ranging from yellowing to death and abscission (Valencia et al., 2008).

A method of determining genetic chloride exclusion in soybean was developed to identify varieties that express this unique characteristic (Rupe et al., 2000). A protocol was established in which soybean roots are hydroponically introduced to high levels of chloride salts to initiate a chloride exclusion or inclusion response within each plant. Leaf tissue is then analyzed for chloride content and compared to known checks and standards to determine the degree of chloride sensitivity for each variety.

Soybean producers, soybean breeders, and sales and extension personnel must know the tolerance status of a soybean variety to make an appropriate selection for soybean production or soybean breeding. Therefore, the objective of this study was to evaluate soybean varieties in the University of Arkansas System Division of Agriculture' Crop Variety Improvement Program for their tolerance or susceptibility to elevated chloride levels.

Procedures

In 2017 through 2019, between 187 and 212 soybean varieties from maturity groups 4 (MG 4) and 5 (MG 5) respectively, were received from the Arkansas Crop Variety Improvement Program and subjected to elevated concentrations of chloride salts while cultivated in an aerated root immersion hydroponic system. A period of chloride exposure was followed by laboratory analysis of leaf tissue for chloride content (Rupe et al., 2000). Of the varieties received, 67%, 68%, and 80% were from MG 4 in 2107, 2018, and 2019, respectively.

The testing procedure was conducted in a greenhouse to minimize outside environmental variations. Soybean varieties were planted from seed into flats containing Metro Mix soil media (Sun Gro Horticulture, Agawam, Mass.).

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Throughout the germination process, only tap water was added to the soil media as needed to maintain adequate soil moisture. Upon reaching the vegetative cotyledon (VC) growth stage, the soybean plants were carefully removed from the soil media. The roots of each plant were washed with tap water and trimmed to approximately 1.5–2.0-in. in length. This root trimming allowed the seedlings to be inserted into small holes created in styrofoam insulation boards (The Dow Chemical Company, Midland, Mich.) covering plastic MacCourt Super Tubs (MacCourt Products, Inc., Denver, Colo.). Five plants (replications) from each variety were transplanted into the hydroponic system.

The plastic tubs were the basis of the hydroponic system and were filled with deionized water. The styrofoam boards supported the soybean plants by their cotyledons and allowed them to be suspended in the hydroponic system. A Sweetwater regenerative blower (Pentair, Ltd., Schaffhausen, Switzerland) was used to provide aeration to the plant roots through a perforated x-pipe placed in the bottom of each tub. Each x-pipe was constructed of 0.63 in. PVC pipe and drilled with several 0.125-in. holes to provide the plant roots with oxygen.

After transplanting soybean varieties into the hydroponic system, the plants were allowed to acclimate in the deionized water. After a two-day adjustment period, a modified Johnson nutrient solution (Johnson, 1980) was added to each tub (Table 1). This nutrient solution provided the soybean plants with essential elements (Sigma-Aldrich, St. Louis, Mo.) required for healthy and stress-free growth.

A chloride salt solution (Table 2) was added to the hydroponic tubs after the plants had reached the V3 growth stage. The salt solution contained a blend of calcium chloride and sodium chloride (Sigma-Aldrich, St. Louis, Mo.). This solution mimics the natural chloride salt deposits commonly found in affected groundwater in Arkansas and was added in three parts at 48-hour intervals to gently bring the total combined nutrient and salt solution to 50 mmol chloride concentration. After maintaining a 50 mmol chloride concentration in the hydroponic system for 72 hours, the two uppermost fully developed trifoliate leaves from each plant were collected and stored in coin envelopes until analyzed.

Leaf tissue samples were dried in a gravitational laboratory oven at 140 °F for 24 hours. After drying, each sample was individually ground in a Wiley laboratory mill passing through a 20 mesh (0.033 in.) sieve (Thomas Scientific, Swedesboro, N.J.)

A 100 mg sample of ground leaf tissue was placed into 250-ml Erlenmeyer Pyrex flasks (Corning, Inc., Corning, N.Y.) containing 50 mL of deionized water for chloride extraction. The flasks were placed on an orbital shaker at 100 rpm for 20 minutes. The extracted samples were filtered through a Whatman #1 qualitative filter paper and into 125-mL wide-mouth plastic bottles.

A 3-mL aliquot of each leaf tissue sample extract and 1 mL of weak acid reagent (acetic and nitric acid) were placed into small glass vials. This leaf tissue chloride extract was tested for chloride content using a Haake-Buchler digital chloridometer (Buchler Instruments, Inc., Saddlebrook, N.J.) in low power mode.

The digital chloridometer was calibrated before each batch of samples by using a 50-ppm chloride standard solution. Control check samples, a known includer soybean variety, and a known excluder soybean variety were placed within each test batch for quality control purposes.

Results and Discussion

After exposure to an elevated concentration of chloride salts, leaf tissue chloride content provided a valuable tool in discerning the genotypic response of each soybean plant and provided a background for determining the inherent degree of sensitivity to chloride (Lee et al., 2004). A dividing line emerged between plants with relatively low levels of chloride in their leaf tissue compared to those having high concentrations.

Chloride sensitivity was directly correlated to levels of leaf tissue chloride concentration. Plants with low levels of leaf tissue chloride exhibited the genetic trait of chloride exclusion, while those with much higher levels expressed the chloride inclusion trait. These were labeled "excluders' and "includers" respectively (Abel, 1969). Plants with low levels of leaf tissue chloride (less than 5,000 ppm chloride) exhibited the genetic trait of chloride exclusion, while those with higher levels (greater than 5,000 ppm chloride) expressed the chloride inclusion trait.

The response of each plant within a variety did not necessarily predict the collective response of the variety as a whole. This suggests some degree of genetic diversity within certain varieties, but since varieties are grown as a collection of individual plants, the response to chloride for each plant was summed as a varietal whole. Therefore, a classification of chloride excluder was made for soybean varieties in which every individual plant within the variety contained low levels of leaf tissue chloride. A chloride includer response was noted when all plants within a variety contained relatively high concentrations of leaf tissue chloride. Some varieties of soybean had a mixed genotypic response when their roots were introduced to high levels of chloride. With this response, some plants contained within the specific variety had low levels of leaf tissue chloride, while others contained high levels. This suggested some possible genetic variation, and these were categorized as mixed reaction varieties. Soybean chloride tolerance has been noted to originate from pedigrees found more commonly in MG 5 varieties than among MG 4 varieties (Lee et al., 2004).

As expected, a higher percentage of chloride excluders were observed among MG 5 varieties (Table 3). In 2019, 28%, 59%, and 13% of the MG 4 varieties were rated as excluder, includer, and mixed, respectively, while among the MG 5 varieties, 31%, 53%, and 16% were rated as excluder, includer, and mixed, respectively. However, when looking at the 3-year average (2017 to 2019), 31% of the MG 4 varieties were rated as excluders, while 42% of the MG 5 varieties were rated as excluders (Table 3). Identifying the chloride injury response of each variety provides data required for the selection and advancement of chloride exclusion traits.

Practical Applications

Most Arkansas soybean producers have excellent potential for profitable yields, but still need to be mindful of the limiting factor that chloride toxicity may cause with select varieties. Screening soybean varieties grown within the state for sensitivity to chloride salts provides a tool for growers to use when choosing the best varieties for their particular field conditions. The data provided from this project helps to ensure the profitability and security of Arkansas soybean production by reducing chloride-induced yield limitations through better genetic selection.

Acknowledgments

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Table 1. Modified Johnson Nutrient Solution.

Nutrient/Element	Final Nutrient Concentration	Final Nutrient Concentration	Source of Nutrient
Macronutrient Solution			
	mmol	ppm	
N	7.0	98.0	KNO_3, $Ca(NO_3)_2$
P	1.0	31.0	KH_2PO_4
K	4.0	156.4	KH_2PO_4, KNO_3
Ca	2.0	80.2	$Ca(NO_3)_2$
Mg	1.0	24.3	$MgSO_4$
S	1.0	321.0	$MgSO_4$
Micronutrient Solution A			
	µmol	ppm	
B	50.0	0.54	H_3BO_3
S	12.5	0.40	$MnSO_4$, $ZnSO_4$, $CuSO_4$
Mn	10.0	0.55	$ZnSO_4$
Zn	2.0	0.13	$MnSO_4$
Na	1.0	0.02	Na_2MoO_4
Cu	0.5	0.03	$CuSO_4$
Mo	0.5	0.05	Na_2MoO_4
Micronutrient Solution B			
	µmol	ppm	
N	100.0	1.40	$C_{10}H_{12}N_2O_8FeNa$
Fe	50.0	2.79	$C_{10}H_{12}N_2O_8FeNa$
Na	50.0	1.15	$C_{10}H_{12}N_2O_8FeNa$

Table 2. Chloride salt solution.

Element	Final Element Concentration	Final Element Concentration	Source of Element
	mmol	ppm	
Cl	50.0	1773	$CaCl_2$, NaCl
Ca	20.0	802	$CaCl_2$
Na	10.0	230	NaCl

Table 3. Percent chloride response by maturity group (MG) during a 3-year period 2017 to 2019.

Maturity Group	Excluder	Includer	Mixed	Number of varieties tested
	2017			
	---------------------%----------------------			
MG 4	35	51	14	140
MG 5	50	38	12	70
	2018			
MG 4	30	63	7	145
MG 5	45	45	10	67
	2019			
MG 4	28	59	13	149
MG 5	31	53	16	38
	3-year average (2017–2019)			
MG 4	31	58	11	-
MG 5	42	45	13	-

Preference Assessment of Soybean Traits for its Application in a Public Breeding Program

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Abstract

The objective of this study was to assess the preferences of Arkansas soybean [*Glycine max* (L.) Merr.] farmers for selected traits for soybean varieties to guide the definition of the breeding goals of the University of Arkansas System Division of Agriculture's Soybean Breeding Program. Farmers' preferences can later be used to develop selection indices for the identification of breeding and parental lines to maximize the value of future potential products. We used a discrete choice task approach known as best-worst scaling (BWS) to assess farmers' preferences for 14 soybean traits currently included in the Soybean Breeding Program. We delivered the survey online through the University of Arkansas System Division of Agriculture's Cooperative Extension Service, and directly (face to face) with farmers. Despite our best efforts, to date, we were unable to collect enough observations to conduct a valid analysis. We will continue working on this project during the 2020 crop season with the goal of completing the analysis in the current calendar year.

Introduction

Developing new soybean varieties requires the definition of clear, measurable, and attainable breeding goals. These breeding goals are based on the prioritization of traits based on perceived value, to maximize the usefulness of the new varieties for stakeholders. However since most traits of importance are controlled by many genes, it is very difficult, if not impossible, to combine all possible traits of interest in a single variety. Conversations with different members of the stakeholder group will result in various levels of importance and value for key traits, such as herbicide package, disease or stress tolerance, and modified seed compositions. Under these circumstances, it is imperative to be able to adequately identify, weight, and put economic value to each trait under the current and future market needs.

A very large portion of the University of Arkansas System Division of Agriculture's Soybean Breeding Program funding comes from Arkansas' soybean farmer's checkoff dollars. Therefore, it is the main breeding goal to develop varieties adapted and useful to Arkansas' soybean farmers. This research intends to gather feedback, via surveying key stakeholders from the Arkansas soybean sector, including farmers and seed industry, on the importance, weight, and economic value of key soybean traits in the state of Arkansas. The intent is to use the results from this research in the development of selection indices for the prioritization of the breeding efforts within the University of Arkansas System Division of Agriculture's Soybean Breeding Program.

Procedures

A list of desirable breeding traits was developed by the University of Arkansas System Division of Agriculture's soybean breeding group (Table 1). We used the Best-Worst Scaling approach (BWS) (Louviere and Woodworth, 1990) to assess farmers' preferences for these selected traits. The BWS approach is a scaling approach in which respondents are asked to choose their most preferred and least preferred choices amongst a set of items. By forcing respondents to discriminate between the items in the choice set, BWS has a higher discriminatory rate between items compared to traditional rating scales in which respondents can declare the same degree of importance to multiple items. In BWS, researchers can transform choices into a probability scale that can be analyzed and measured, in contrast to traditional rating scales whose theoretical scaling properties are often unknown (the intervals are often assumed). The BWS surveys provide richer data with less burden on respondents because it collects more information in a simple way (Bazzani et al., 2018; Cohen, 2009).

We designed the experiment to provide robust results with a minimum of 100 responses. We used a Nearly Balanced Incomplete Block Design (BIBD) to organize the 14 soybean

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breeding traits into 14 choice sets, with each choice set containing seven traits. The BIBD ensures that the occurrences and reoccurrences of the objects within the choice sets are constant, that is, each object appears the same number of times in each choice set, thereby reducing the possibility of respondents making unintended assumptions about the objects based on their arrangements in the design.

Three versions of the questionnaire were designed in which the sequence of the choice sets and the items within the choice sets were randomized in order to achieve randomization and control for any effect of the order of choice sets (Cohen, 2009). Table 2 illustrates an example of one of our choice sets. Respondents were asked to select the least and most important attribute among the seven soybean breeding traits shown in each choice set.

The survey was made available online at the University of Arkansas System Division of Agriculture's Cooperative Extension Service webpage (https://www.uaex.edu/media-resources/news/august2019/08-16-2019-Ark-soybean-survey.aspx) in August 2019, and publicized at several industry events throughout the state, including the 2019 Rice field day, the 2020 Tri-State Soybean Forum, and the 2020 Arkansas Farm Bureau Winter Meeting.

Results and Discussion

Despite our best effort, to date, we gathered only 10 responses, far from the at least 100 responses needed to conduct a meaningful statistical analysis. We will continue reaching out to Arkansas soybean farmers during the 2020 crop season to build a sample that will allow us to conduct this important study.

Practical Applications

The findings of this study will help the Soybean Breeding Program to define the most important breeding goals based on the preferences of farmers, maximize the usefulness of the new varieties for stakeholders, and improve the return on investment in the program.

Acknowledgments

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Table 1. Selected soybean breeding traits and definitions.

Traits	Definitions
Herbicide trait: Conventional	No transgenic herbicide traits. Conventional soybean production.
Herbicide trait: Glyphosate-tolerant	Transgenic soybeans tolerant to glyphosate only (commercially available as Roundup Ready® or Glyphosate Tolerant).
Herbicide trait: Stacked herbicide traits	Transgenic soybeans with stacked traits for multiple herbicide tolerances. For instance, Xtend®-RR2Y, Enlist®-RR, Liberty™-RR, among others.
Yield: 90–97% of best alternative variety	Yield level within 90%–97% of best alternative variety. For instance, if best alternative variety yields 60 bu./ac, proposed yields would be within 54–58 bu./ac range.
Yield: same as best alternative variety	Yield level comparable to best alternative variety (within 2%). For instance, if best alternative variety yields 60 bu./ac, proposed yields would be within 59–61 bu./ac range.
Yield: more than 103% of best alternative variety	Yield level more than 3% better than best alternative variety. For instance, if best alternative variety yields 60 bu./ac, proposed yields would be greater than 62 bu./ac range.
Maturity Group: 4-Early	Early maturity group 4 (MG 4.0–4.4). Early maturing varieties of group 4, similar to Pioneer's P40A03L or P43A42X, or Asgrow's AG42X6 or AG43X8.
Maturity Group: 4-Late	Late maturity group 4 (MG4.5–4.9). Later maturing varieties of group 4, similar to Pioneer's P45A29L or P47T89R, or Asgrow's AG46X6 or AG48X9.
Maturity Group: 5	Fuller season varieties, maturity greater than 5.0 (MG 5.0–5.9). Typically of determinate type. Similar to Pioneer's P52A43L or 95Y70, or Asgrow's AG52X9 or AG55X7.
Grain Quality: less than 2% damage	Damaged seed includes heat damage, frost damage, immature seed, mold damage, insect damage, and sprout damage. Producers are allowed up to 2% damaged beans before damage discounts apply (U.S. Grade 1 soybeans).
Grain Quality: more than 54 lb/bu.	Test weight measured in lb/bu., with a standard test weight of 60 lb/bu. used to convert the scale weight of soybean loads to the number of bushels contained in the load, even if the actual test weight of the load is lower than 60 lb/bu. Grain buyers will apply discounts when test weight falls below 54 lb/bu.
Tolerance to: Stem Canker	Soybean rated resistant or moderately-resistant to Stem Canker by field screening.
Tolerance to: Frogeye Leaf Spot	Soybean rated resistant or moderately-resistant to Frogeye Leaf Spot by field screening.
Tolerance to: at least one race of cyst nematode	Soybean rated resistant or moderately-resistant to at least one race (HG type) of soybean cyst nematode by greenhouse screening.
Tolerance to: chloride	Soybean rated excluder by greenhouse screening.
Tolerance to: at least one race of root-knot nematode	Soybean rated resistant or moderately-resistant to at least one race of Soybean Root-Knot Nematode by greenhouse screening.
Tolerance to: flood	Soybean rated "better than average" for chlorosis and survival when flooded with 4 in. of water for 10 days at early vegetative stages (V3).
Tolerance to: drought	Soybean rated "better than average" for wilting when grown under non-irrigated conditions and rated at full bloom (R2).
Lodging: less than 45 degrees	Crop lodges less than 45°, making it easier to combine.
Lodging: more than 45 degrees	Crop lodges more than 45°, making it harder to combine.
Seed Composition: enhanced/modified	Soybean seed with enhanced protein levels (>45%), or with enhanced oil levels (>20.5%), or with enhanced protein meal levels (>50%), or with high oleic acid levels (>70%), among other possible traits.
Seed Composition: not enhanced/modified	Soybean seed with no enhancements in protein levels, oil levels, protein meal levels, or oleic acid levels, among other possible traits.

Table 2. Example of a choice set used in this study.

Choose a trait you consider the most important and a trait you consider the least important.		
Most Important	**Traits**	**Least Important**
	Yield: 90–97% of best alternative variety	
	Grain Quality: more than 54 lb/bu.	
	Lodging: more than 45°	
	Maturity Group: 4-early	
	Tolerance to: stem canker	
	Herbicide Trait: glyphosate-tolerant	
	Seed Composition: enhanced/modified	

Breeding Soybean Cultivars in Arkansas with High Yield and Disease Resistance

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Abstract

The goal of the University of Arkansas System Division of Agriculture's Soybean Breeding Program is developing maturity group (MG) 4 and early 5 soybean [*Glycine max* (L.) Merr.] varieties with high yield, appropriate disease-resistant package, specialty traits, and good adaptation to Arkansas growing conditions. The program has released numerous conventional and glyphosate-tolerant varieties. The breeding process encompasses the identification of parents for crossing through the selection of high-yielding elite and germplasm lines from different public programs, exotic germplasm, and off-patent varieties from the U.S. National Plant Germplasm System. Breeding populations are advanced until a high percentage of homozygosity is reached. Then, single plants are selected and individually grown as progeny rows. Rows with the best overall field performance are selected and evaluated in preliminary and advanced yield trials across Arkansas. The most promising lines are subsequently entered in the Arkansas Soybean Performance Tests, the USDA Uniform Soybean Tests Southern States, and other official variety testing programs. In 2019, release proposals for three MG 4 conventional lines and one MG 5 early glyphosate-tolerant line were submitted for consideration.

Introduction

The University of Arkansas System Division of Agriculture's Soybean Breeding Program aims to develop soybean varieties with high yield, disease resistance, improved seed composition, and good adaptation to Arkansas growing conditions. Historically, our focus was to develop maturity group (MG) 5 soybeans; however, thanks to our continued breeding efforts during the past three years, the proportion of conventional MG 4 materials in the program has been steadily increasing.

The breeding program has publicly released ten soybean varieties in the last two decades. Among our previous released varieties, Ozark (Chen et al., 2004), Osage (Chen et al., 2007), UA 5612 (Chen et al., 2014a), UA 5213C (Chen et al., 2014b), UA 5014C (Chen et al., 2016), UA 5814HP (Chen et al., 2017), and UA 5615C have been commercially produced and have been used for variety and germplasm development by other breeding programs. Additionally, Osage and UA 5612 have been used as yield checks in the USDA Uniform Soybean Tests, Southern States. Here, we report our breeding flow for the development of new MG 4 and MG 5 commercial soybean varieties.

Procedures

The breeding objective of the soybean breeding program is to combine the best traits from different soybean varieties and/or lines to release high-performing varieties well adapted to Arkansas. We use conventional breeding and Marker Assisted Selection (MAS) in tandem to identify desirable traits and improve and shorten the breeding process. Our breeding scheme encompasses: 1) identification and selection of high-yielding parents with complementary traits of interest for cross and population development, 2) advancement of breeding populations for three or four generations to allow genetic recombination, and 3) selection of best-performing lines with the traits of interest, followed by multi-location evaluation across several years. In 2019 we made 197 different cross combinations. Plant populations in early generations were advanced using a modified bulk-pod descend method, and 12,400 $F_{4:5}$ progeny rows were evaluated for adaptation and agronomic performance. Off-season nurseries were used to accelerate the breeding process. First-year yield trials were grown in 4 Arkansas locations in non-replicated tests. Advanced yield trials were grown in 5 Arkansas locations with 2 replications. Lines with superior performance were entered

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in the Arkansas Soybean Variety Performance Tests, and the USDA Uniform Tests, Southern States; concomitantly, breeder seed is produced and subsequently provided for foundation seed production in anticipation of variety release. Pre-commercial lines were screened for disease resistance to soybean cyst nematode, root-knot nematode, sudden death syndrome, stem canker, and frogeye leaf spot under either greenhouse or field conditions.

Results and Discussion

Five high-yielding lines were evaluated in the 2019 USDA Uniform Preliminary MG 5 Soybean Tests, Southern States. Similarly, 5 advanced lines were evaluated in the Advanced MG 5 stage of these tests. Arkansas' entries in the Uniform Preliminary test yielded between 44.5 and 53.2 bu./ac (85%–103% check yield), and the line R16-378 was ranked 1st place overall, with 53.2 bu./ac yield. The five Arkansas' lines in the Uniform test yielded between 53.6 and 60.1 bu./ac (93%–105% check yield).

Three conventional promising lines were entered in the 2019 Arkansas Soybean Performance MG 4 Late Test (Non-Extend varieties), and they yielded between 56.8 and 61.8 bu./ac (89%–97% test mean). Also, nine conventional and one glyphosate-tolerant promising lines were entered in the 2019 Arkansas Soybean Performance MG 5 Test (Non-Extend varieties). Lines yielded between 59.2 and 65.5 bu./ac (95%–105% test mean) and R16-1445, R15-1587, and R13-13997 ranked 1st, 2nd, and 4th place with 65.5, 64.7, and 64.0 bu./ac, respectively.

Also, we yield-tested 781 MG 4 and 375 MG 5 conventional lines, and 70 MG 5 glyphosate-tolerant lines in advanced and preliminary yield trials in Arkansas in 2019. Overall, approximately 46% of the conventional commodity lines in yield testing were of MG 4, and approximately 54% were of MG 5, with only 11 lines (out of 1888 tested) being MG 6 (Fig. 1). In 2019, 92% of the variety development program was conventional (859 entries), and 8% were glyphosate-tolerant (76 entries) lines. The following is the summary by testing stage in 2019: we had 32 pre-commercial, 171 advanced, and 985 preliminary conventional lines. Additionally, in 2019 we had one pre-commercial, 10 advanced, and 60 preliminary glyphosate-tolerant lines. Additionally, 10,581 single plants were pulled from F_3–F_4 breeding populations and will be evaluated as progeny rows (Table 1).

Practical Applications

We strive to provide Arkansas farmers with high-yielding locally-adapted varieties at a low cost. The continued release of conventional and glyphosate-tolerant public varieties such as Ozark, UA 4805, Osage, UA 5612, UA 5213C, UA 5014C, UA 5414RR, and UA 5715GT offers low-cost seed for Arkansas growers and also provides sources of germplasm for breeding programs in the U.S.

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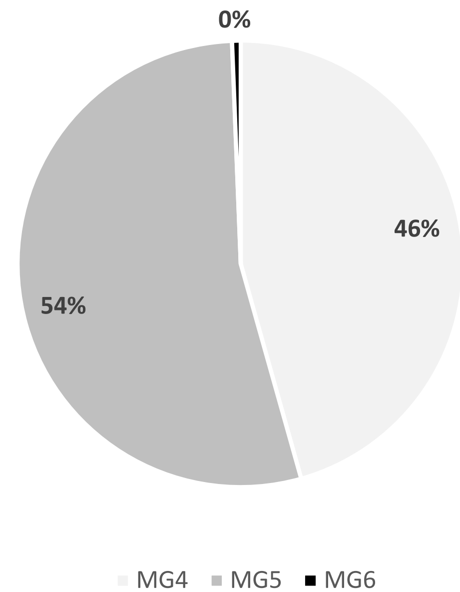

Fig. 1. Conventional entries by maturity group evaluated in 2019 yield trials in the University of Arkansas System Division of Agriculture's Soybean Breeding Program.

Table 1. Overview of the University of Arkansas System Division of Agriculture's Soybean Breeding and Genetics Program tests in 2019.

Testing Stage	Entries
USDA Uniform/Preliminary Tests	10
AR Variety Testing Program	13
Arkansas Advanced Lines	181
Arkansas Preliminary Lines	1045
Progeny Rows	12,400
Breeding Populations (F_1 – F_4)	570
New Crosses	197

Breeding Soybean Under Reduced Irrigation Conditions

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Abstract

Sustainability of soybean [*Glycine max* (L.) Merr.] production is challenged by drought. Irregularity of precipitation and water quality issues exacerbate the situation in Arkansas. To overcome this challenge, the University of Arkansas System Division of Agriculture's Soybean Breeding Program develops germplasm with a slow-wilting trait. This study aimed to assess if reduced irrigation, triggered at various reproductive stages, would influence variety selection decisions. The experiment was conducted as an Augmented Strip Plot in two locations. Different irrigation levels were triggered in two breeding populations using an atmometer at designated growth stages. Canopy wilting, Normalized Difference Vegetation Index (NDVI), maturity, and yield were evaluated. Analysis of variance (ANOVA) for each trait showed highly significant differences among irrigation levels, between populations, and for their interaction. These results will help soybean breeders make selection decisions on breeding lines for reduced irrigation.

Introduction

Approximately 85% of total soybean [*Glycine max* (L.) Merr.] acres in Arkansas are produced under irrigation, with watering initiated typically at early reproductive stages (AFBF, 2019). Facing irregular precipitation, high temperatures during summers, and water quality issues, soybean farmers must manage water for profitable and sustainable production. Soybean can suffer a yield loss of up to 40% annually due to drought (Dogan et al., 2007). In that perspective, the University of Arkansas System Division of Agriculture's Soybean Breeding Program develops soybean germplasm with slow-wilting or prolonged-nitrogen (N) fixation that can survive short periods of drought (Manjarrez et al., 2020). The wilting mechanism is related to soil moisture conservation (Fletcher et al., 2007; King et al., 2009), and canopy wilting is the first visible symptom of soil water deficit (Sloane et al., 1990). When the soil is plentiful of water, slow-wilting soybean can maintain lower transpiration rates and, thus, do not deplete the soil moisture reservoir rapidly. Additionally, as the drought progresses, a slow-wilting line can use available moisture to prolong leaf turgor for several days (King et al., 2009). However, there is no knowledge regarding this trait under reduced irrigation. The objective of this study was to assess if different irrigation conditions during reproductive stages influence the selection decisions in populations with and without the slow-wilting trait.

Procedures

Two soybean populations with contrasting wilting traits were used in this experiment. A total of 92 soybean breeding lines with potential for slow-wilting (R11-2933/R11-1057) and 73 soybean breeding lines with potential for fast-wilting (N07-14753/R11-1057) (Fig. 1), were grown in 2019 at the University of Arkansas System Division of Agriculture's Rohwer Research Station near Rohwer and the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart. Populations were planted in 2-row plots, 2.5-ft apart and 15-ft long with a 5-ft alley, as a strip plot in Augmented Design (Fig. 2). Irrigation was triggered at different reproductive stages (R1, R2, R3, and R4) using an atmometer (Henry et al., 2014). Composite soil samples were taken from each block to analyze soil chemical properties. A matched-paired test was conducted to analyze the data. The wilting score was visually rated on a scale from 0 (no wilting) to 9 (plant death). A DJI Matrice 200 platform (DJI, Shenzhen, China) was used with a MicaSense RedEdge Multispectral sensor to output NDVI (MicaSense, Seattle, Wash.). Maturity was taken based on the date on the Julian calendar, and yield was assessed at harvest. Images from the unmanned aerial vehicle were processed with PIX4DMapper v. 4.5 (Pix4D S.A., Prilly, Switzerland), and NDVI per plot was calculated using zonal statistics in QGIS v. 3.10.0 (QGIS.ORG, Grut, Switzerland). Data were analyzed separately for

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each location in JMP Pro v.14 (SAS Institute, Cary, N.C.) using an analysis of variance. Fixed effects were soybean population, irrigation levels, and interaction between irrigation levels and soybean population. Block was considered a random factor. A least-square mean contrast was performed under each irrigation level to compare fast and slow-wilting soybean.

Results and Discussion

Soil chemical proprieties including pH, electrical conductivity (EC), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), sodium (Na), iron (Fe), manganese (Mn), copper (Cu), boron (B), loss on ignition (LOI), nitrogen (N), and carbon (C) revealed no significant difference between pre and post soil samplings in each block in both locations, except for electrical conductivity (EC). The interaction between irrigation levels and soybean population was significant for wilting and maturity, but not NDVI and yield. Results showed highly significant differences among irrigation levels for each agronomic trait. Wilting intensified as the irrigation was delayed. The fast-wilting population had a higher wilting score compared to the slow-wilting one. Also, NDVI increased as it refers to the canopy coverage of soybean at different reproductive stages even when irrigation was delayed. This same pattern was observed for both fast and slow-wilting soybean, without difference between populations. Delayed irrigation resulted in delayed maturity in 2019, probably because a lack of water could have resulted in delayed phenological development. Fast-wilting lines matured earlier than slow-wilting ones. Among different irrigation levels, significant yield differences were observed between the initiation of irrigation triggered at R3 and R4 stages. However, there was no significant difference in yield between fast- and slow-wilting soybean. This experiment will be repeated in the summer of 2020 for confirmation of these results.

Practical Applications

Understanding the effects of mild drought on populations with fast- and slow-wilting traits are important to define the breeding objectives and corresponding deployment of breeding lines under reduced irrigation conditions.

Acknowledgments

We thank the Arkansas Soybean Promotion Board for funding the project and the University of Arkansas System Division of Agriculture personnel at the Rohwer Research Station and the Rice Research And Extension Center near Stuttgart for their hard work to accomplish this research.

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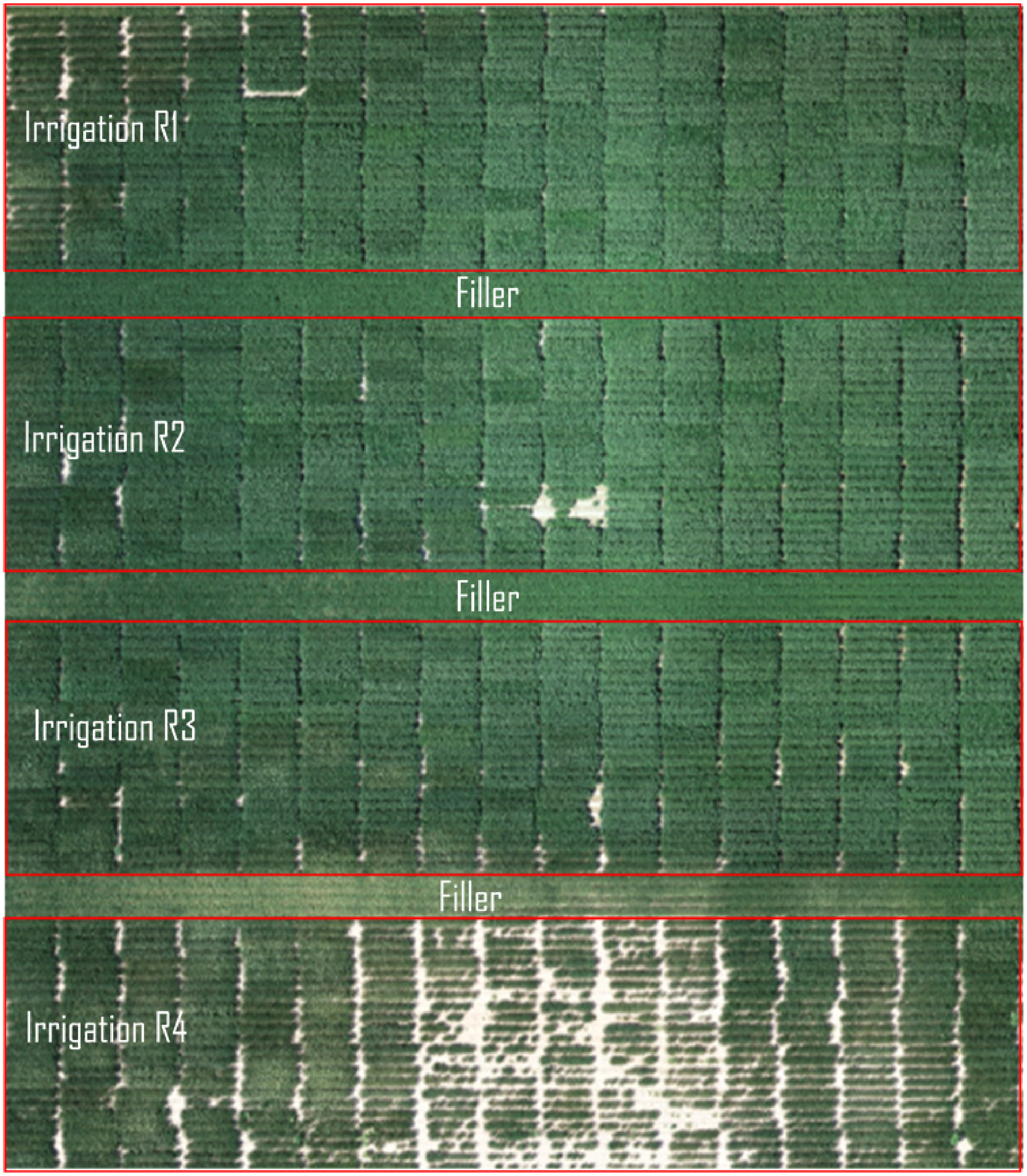

Fig. 1. Aerial view of the different irrigation levels at the University of Arkansas System Division of Agriculture's Rohwer Research Station near Rohwer, Ark. when the soybean crop was at R4 (at least one ¾-in.-long pod in upper four nodes) physiological stage.

Fig. 2. Fast-wilting soybean line (left) and slow-wilting soybean line (right).

Soybean Germplasm Enhancement Using Genetic Diversity

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Abstract

The Soybean Breeding Program of the University of Arkansas System Division of Agriculture constantly introduces diverse and/or exotic germplasm into elite Arkansas lines to develop and release soybean [*Glycine max* (L.) Merr.] varieties and germplasm with early maturity (Maturity Group 4), high yield, wide adaptation, disease resistance, and abiotic stress tolerance. In 2019, the program advanced three promising, high-yielding lines (R13-11034, R15-7063, and R15-7171), two drought-tolerant lines (R13-12468 and R16-4053), and one disease-resistant line (R16-4235) derived from diverse exotic germplasm. These lines were evaluated in the USDA Uniform Soybean Tests, Southern States, and will be potential germplasm releases as well as parental sources in second-generation breeding crosses for the development of commercial products. Also, multiple breeding populations were developed and advanced for the introgression of early-maturity and indeterminacy into our breeding program. The sustained development of the Soybean Breeding Program in Arkansas highly depends on these breeding efforts that introduce un-adapted lines with key traits and then support pre-breeding for local adaptation.

Introduction

The introduction of exotic germplasm is vital to the soybean breeding program for germplasm and cultivar development (Carter et al., 1993; Gizlice et al., 1994). In the U.S. soybean community, public breeders have created a very active germplasm exchange system to facilitate access to diverse germplasm for cultivar development. It is imperative to improve soybean's narrow genetic base, which traces back to only 26 ancestors that account for 90% of the total ancestry of commercial cultivars (Gizlice et al., 1994).

The University of Arkansas System Division of Agriculture's Soybean Breeding Program uses diverse and/or exotic germplasm to bring key traits such as early maturity or indeterminacy or to improve soybean genetic diversity for seed yield, drought tolerance, and disease resistance. Five germplasm lines with diverse exotic parentages and yield potential have been released from our breeding program, namely R99-1613F, R01-2731F, R01-3474F (Chen et al., 2011), R10-5086 and R11-6870 (Manjarrez-Sandoval et al., 2018). Similarly, the program has also released germplasm with diversity for disease resistance and abiotic stress tolerance, including R01-416F and R01-581F [improved yield and nitrogen (N) fixation under drought] in 2006 (Chen et al., 2007), and R10-2436 and R10-2710 (high yield under irrigation and low yield reduction under drought) (Manjarrez-Sandoval et al., 2020).

The diverse/exotic germplasm project supports our breeding program by maintaining an active exchange of germplasm with other public breeding programs, and by keeping continuous introduction of new exotic genes in the Arkansas soybean germplasm pool. This report highlights the breeding efforts made in 2019 in the use of diverse and/or exotic germplasm for traits of interest such as maturity, yield, and biotic and abiotic stress tolerance.

Procedures

Every year, a cycle of germplasm-enhancement breeding is started for diverse traits of interest such as early maturity, high yield, drought tolerance, and disease resistance. The breeding scheme includes making cross combinations between our most advanced high-yielding lines and germplasm with an exotic background. Breeding populations are advanced from F_2 to F_4 generation using the modified single-pod descent method (Fehr, 1987). Subsequently, individual plants from F_3 and F_4 breeding populations are selected and individually harvested. Single progeny rows are grown at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Ark., and lines are selected visually based on overall field performance. Lines are yield tested in preliminary and advanced trials in Arkansas and other southern states. Lines with the best ag-

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ronomic performance and target traits are selected as parents for variety-development crosses, and further advanced for potential germplasm release.

Results and Discussion

Yield Improvement Using Genetic Diversity. In 2019, 3 high-yielding lines (R13-11034, R15-7063, and R15-7171) derived from exotic germplasm were evaluated in regional yield trials and increased as pre-foundation seed in Stuttgart and at the University of Arkansas System Division of Agriculture's Milo J. Shult Agricultural Research and Extension Center in Fayetteville, Ark. Twelve advanced lines with diverse or exotic pedigree (12.5% to 50%) were tested in 2-replication trials at five Arkansas locations, yielding 94% to 108% of the check. A total of 160 preliminary lines derived from diverse or exotic pedigree (12.5% to 50%) were evaluated for yield in one-rep trials at four Arkansas locations. Thirty-three high-yielding lines with 100% to 117% of check yield and 12.5% to 50% diverse/exotic pedigree were selected for the 2020 intermediate diversity yield trials. A total of 44 lines derived from diverse pedigrees were also selected from the 2019 progeny row for the 2020 preliminary tests. In addition, a total of 1199 single plants were selected from five F_3 and two F_4 breeding populations and threshed for the 2020 progeny row test. We also advanced 10 F_4, 10 F_3, 11 F_2, and 34 F_1 breeding populations and made 12 new cross combinations with high-yielding and diverse/exotic pedigrees for this genetic diversity project.

Disease Resistance. Line R17-2442, with potential for reniform nematode resistance, was selected for the 2020 USDA Preliminary Soybean Maturity Group 5 Early (MG5E) Tests. Seven lines with diverse pest and disease genes were tested in advance yield trials in 2-replication trials at 5 Arkansas locations. A total of 110 preliminary lines with exotic Phomopsis resistant pedigree were evaluated for yield in one-replication trials at four Arkansas locations, of which 22 lines with 90% to 123% check yield were selected for the 2020 intermediate test. Forty-seven lines with diverse pest and disease resistant pedigree (sudden death syndrome and soybean cyst nematode) were also selected from 2019 progeny rows for the 2020 preliminary trials. We also advanced 7 F_4, 5 F_3, 6 F_2, and 2 F_1 breeding populations and made 4 new crosses for the pest and disease resistant project. All diverse lines selected for yield trials of the germplasm enhancement project were shown in Table 1.

Practical Applications

The University of Arkansas System Division of Agriculture's Soybean Breeding Program has made significant progress in the development of locally adapted and value-added breeding lines, germplasm, and cultivars with diverse genetic traits for yield, abiotic and biotic stress tolerance, and resistance through the exotic gene pool. The program also integrates these necessary diverse genetic traits into the parental stock through germplasm exchanges with other breeding programs. In addition, our program provides diverse genotypes to other public soybean breeding programs for variety development purposes.

Acknowledgments

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Table 1. Germplasm enhancement project overview in 2019.

Test	Multi-state stage entries	Advanced stage entries	Preliminary stage entries
	-----------------------------	number	-----------------------------
High Yielding/Early Maturity	3	12	160
Disease Resistance	1	16	110

Purification and Production of Pre-Foundation and Breeder Seed for the University of Arkansas System Division of Agriculture's Soybean Breeding Lines

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Abstract

The University of Arkansas System Division of Agriculture's Soybean Breeding and Genetics Program together with the Foundation Seed Program strives to develop and release pure, high-yielding soybean [Glycine max (L.) Merr.] varieties and germplasm with diverse traits and local adaptation. The seed purification is accomplished by efforts made in line grow-outs, reselections, and rouging for off-types in each year. Our Purity and Foundation Seed Programs guarantee breeder- and foundation-level seed resources of current and future variety releases for regional soybean dealers and farmers. This report summarizes the purification and production efforts made during the 2019 growing season.

Introduction

The University of Arkansas System Division of Agriculture's Soybean Breeding and Genetics Program develops and releases soybean varieties with high yield, tolerant/resistant to major biotic and abiotic stresses, and locally adapted. Producing seeds with a high level of genetic purity during the breeding process is critical. The University of Arkansas System Division of Agriculture's Foundation Seed Program collaborates with the Soybean Breeding Program for the production of breeder-, foundation- and certified seed classes as listed in the Official Standards for Seed Certification in Arkansas (Arkansas State Plant Board, 2013). The following are the purification efforts that took place in 2019, thanks to the sponsorship of the Arkansas Soybean Promotion Board.

Procedures

The Soybean Breeding Program and the Foundation Seed Program grow breeder seed rows and foundation seed increases at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Ark. All lines are rogued in-season for flower color, pubescence color, pod color, maturity, and plant height. Isolation of grow-outs is utilized as required by the seed class to be produced.

Results and Discussion

In 2019, a total of 91 pre-commercial lines were grown for breeder seed production and purification. The 8 most promising lines were grown in 0.1-ac blocks in isolation to produce foundation-grade seed for 2020 Foundation Seed Program, while the other advanced lines (90 conventional and 1 glyphosate-tolerant line) were grown in 0.01–0.1 ac blocks with no isolation to produce breeder seed for 2020 Purity Program. Among the conventional lines, 3 had genetic diversity, 6 lines had improved seed composition, 4 had the tolerance to biotic/abiotic stresses, and 59 were food-grade lines including natto and large-seeded vegetable soybean lines (Table 1).

Practical Applications

The production and purification of breeder and foundation seed provide high-quality seed to local soybean seed producers, enhancing the competitiveness of Arkansas soybean in both the national and international markets.

Acknowledgments

The authors would like to acknowledge the financial support of the Arkansas Soybean Promotion Board. We also thank the University of Arkansas System Division of Agriculture's Research Station staff and technicians for their help and support.

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Table 1. Pre-foundation and breeder seed production and purification overview at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Ark.

Test	Name	Project	Acres Planted	Purified Seed Produced
				lb
Foundation	UA 5414RR	Roundup Ready	70.0	
Foundation	UA 5715GT	Roundup Ready	35.0	
Foundation	UA 5014C	Conventional	19.0	
Foundation	Osage	Conventional	19.0	
Breeder seed	R16-259	Conventional	0.10	70
Breeder seed	R16-253	Conventional	0.10	70
Breeder seed	R15-2422	Conventional	0.10	70
Breeder seed	R17C-1266	Conventional	0.10	70
Breeder seed	R15-1587	Conventional	0.10	70
Breeder seed	R16-2546	Conventional	0.10	70
Breeder seed	R16-39	Conventional	0.10	70
Breeder seed	R16-2547	Conventional	0.10	70
Breeder seed	R13-818	Conventional	0.10	70
Breeder seed	R14-1422	Conventional	0.10	70
Breeder seed	R13-13997	Conventional	0.10	70
Breeder seed	R16-1445	Conventional	0.10	70
Breeder seed	R16-378	Conventional	0.10	70
Breeder seed	R15-1150	Conventional	0.01	15
Breeder seed	R15-1194	Conventional	0.01	15
Breeder seed	R13-1409	Conventional	0.01	15
Breeder seed	R14-898	Conventional	0.01	15
Breeder seed	R15-489	Conventional	0.01	15
Breeder seed	R13-14635RR	Roundup Ready	0.10	70
Breeder seed	R16-7045	Seed Composition	0.10	70
Breeder seed	R16-8295	Seed Composition	0.10	70
Breeder seed	R16-6024	Seed Composition	0.01	15
Breeder seed	R16-6270	Seed Composition	0.01	15
Breeder seed	R16-6274	Seed Composition	0.01	15
Breeder seed	R15-5695	Seed Composition	0.01	15
Breeder seed	R16-4235	Abiotic Resistance	0.10	70
Breeder seed	R16-45	Abiotic Resistance	0.10	70
Breeder seed	R13-12468	Abiotic Resistance	0.10	70
Breeder seed	R16-4053	Abiotic Resistance	0.10	70
Breeder seed	R07-6669	Abiotic Resistance	0.01	15
Breeder seed	R13-11034	Diversity	0.01	15
Breeder seed	R15-7063	Diversity	0.01	15
Breeder seed	R15-7171	Diversity	0.01	15
Breeder seed	R08-4004	Food Grade	0.10	70
Breeder seed	UA Kirksey	Food Grade	0.10	70
Breeder seed	R15-4655	Food Grade	0.01	15
Breeder seed	R16-5860	Food Grade	0.01	15
Breeder seed	R17-3385	Food Grade	0.01	15
Breeder seed	R17-3349	Food Grade	0.01	15
Breeder seed	R17-3171	Food Grade	0.01	15
Breeder seed	R17-3165	Food Grade	0.01	15
Breeder seed	R17-3273	Food Grade	0.01	15
Breeder seed	R17-3252	Food Grade	0.01	15
Breeder seed	R17-3373	Food Grade	0.01	15
Breeder seed	R17-3362	Food Grade	0.01	15
Breeder seed	R09-4357	Food Grade	0.01	15
Breeder seed	R10-8247	Food Grade	0.01	15
Breeder seed	R16-5054	Food Grade	0.01	15

Continued.

Table 1. Continued.

Test	Name	Project	Acres Planted	Purified Seed Produced
				lb
Breeder seed	R16-4761	Food Grade	0.01	15
Breeder seed	R13-5174	Food Grade	0.01	15
Breeder seed	R15-4700	Food Grade	0.01	15
Breeder seed	R15-8156	Food Grade	0.01	15
Breeder seed	R14-6789	Food Grade	0.01	15
Breeder seed	R16-5867	Food Grade	0.01	15
Breeder seed	R14-7048	Food Grade	0.01	15
Breeder seed	R14-7075	Food Grade	0.01	15
Breeder seed	R13-6494	Food Grade	0.01	15
Breeder seed	R13-6912	Food Grade	0.01	15
Breeder seed	R11-12110	Food Grade	0.01	15
Breeder seed	R15-4713	Food Grade	0.01	15
Breeder seed	R17-3208	Food Grade	0.01	15
Breeder seed	R17-3324	Food Grade	0.01	15
Breeder seed	R17-3144	Food Grade	0.01	15
Breeder seed	R17-3368	Food Grade	0.01	15
Breeder seed	R17-3214	Food Grade	0.01	15
Breeder seed	R17-3160	Food Grade	0.01	15
Breeder seed	R17-3156	Food Grade	0.01	15
Breeder seed	R17-3338	Food Grade	0.01	15
Breeder seed	R12-9291	Food Grade	0.01	15
Breeder seed	R16-8464	Food Grade	0.01	15
Breeder seed	R10-8126	Food Grade	0.01	15
Breeder seed	R11-10806	Food Grade	0.01	15
Breeder seed	R12-8218	Food Grade	0.01	15
Breeder seed	R06-3495	Food Grade	0.01	15
Breeder seed	R14-5734	Food Grade	0.01	15
Breeder seed	R16-5506	Food Grade	0.01	15
Breeder seed	R16-5065	Food Grade	0.01	15
Breeder seed	R05-2734	Food Grade	0.01	15
Breeder seed	R10-8560	Food Grade	0.01	15
Breeder seed	R14-5377	Food Grade	0.01	15
Breeder seed	R16-5108	Food Grade	0.01	15
Breeder seed	R16-4880	Food Grade	0.01	15
Breeder seed	R17-3299	Food Grade	0.01	15
Breeder seed	R17-3319	Food Grade	0.01	15
Breeder seed	R17-3314	Food Grade	0.01	15
Breeder seed	R17-3356	Food Grade	0.01	15
Breeder seed	R17-3341	Food Grade	0.01	15
Breeder seed	R17-3328	Food Grade	0.01	15
Breeder seed	R17-3330	Food Grade	0.01	15
Breeder seed	R07-10397	Food Grade	0.01	15

Soybean Variety Advancement Using a Winter Nursery

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Abstract

The Soybean Breeding Program of the University of Arkansas System Division of Agriculture aims to develop and release maturity group (MG) 4 soybean [*Glycine max* (L.) Merr.] varieties with traits of interest and good adaptation to Arkansas. In order to accelerate the advancement of material in the breeding process, the program contracts the services of nurseries for the U.S. winter months. In November 2018, approximately 2500 early-maturing (MG 4) single plants were selected from 13 breeding populations, and thereupon sent to Chile to grow as progeny rows. In April 2019, 614 lines (68% MG 4 and 31% MG 5-early) were selected and bulk-harvested in Chile and sent back for yield evaluation in preliminary trials in multiple Arkansas locations. Two other locations in Missouri and Virginia were also planted. Thanks to this new workflow, it was possible to reduce the breeding process by one year and increase the proportion of MG 4 entries in preliminary testing from 32% to 46% continuing on track towards our breeding goal of reaching 70% MG 4 entries by 2021.

Introduction

The University of Arkansas System Division of Agriculture's Soybean Breeding Program focuses on developing high-yielding conventional MG 4 varieties for Arkansas farmers. The utilization of winter nurseries accelerates the development of new varieties and germplasm by reducing the number of years per breeding cycle (O'Connor et al., 2013). This is critical as the rate of genetic gain is indirectly proportional to the number of years per breeding cycle (Cobb et al., 2019). Thus, variety performance will be greatly affected by the length of time between crossing and release of new product. In this project, progeny rows are grown counter-season in South America (Chile) in an environment similar to Arkansas' growing conditions. There, lines are selected based on their agronomic profile for preliminary testing in Arkansas. By following this workflow, the breeding program is able to save one year in the breeding cycle, which is translated to a larger genetic gain in a shorter time period.

Procedures

There were 2500 single plants selected from 13 genetic populations planted at the University of Arkansas System Division of Agriculture's Vegetable Research Station near Kibler, Ark. Eleven of these populations were developed from crossing high-yielding conventional MG 4 parents (S08-17361/Osage, S09-10871/R05-3239, R12-477/LD10-3482, Md0708WN120/UA5014C, TN09-193/R13-13433, R10-230/LG11-6210, S12-5037/R99-1613F, LG13-4321/R11-7141, R12-4831/S12-3187, LD11-7311/UA5014C, and R11-1578/LD10-3482). In addition, two populations were developed from crossing high-yielding conventional and high-oil soybean (R05-4256/R09-4054 and R12-3616/R11-5131). Plants were individually harvested, seed was cleaned for purity, treated with ApronMaxx® fungicide at label rate, and sent to a winter nursery in Chile (latitude -32.883, longitude -71.248) to be grown as progeny rows during winter 2018-2019. In April 2019, 614 lines (419 MG 4 and 195 MG 5-early) were selected, bulk harvested, and sent back to the U.S. where they were evaluated in multi-location preliminary yield trials in Arkansas, Missouri, and Virginia.

Results and Discussion

Thanks to this project, the Soybean Breeding Program was able to evaluate 614 (68% MG4 and 31% MG 5-early) preliminary lines a year earlier than under the standard workflow. This helped to increase the proportion of MG 4 entries from 32% to 46%, a step closer towards our goal of 70% MG 4 by 2021.

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Practical Applications

The use of a winter nursery to grow soybean lines counter-season decreases the number of years it takes to develop and release varieties to the farmers. It is possible to conduct two cycles of selections on a given calendar year, allowing us to release competitive MG 4 cultivars earlier.

Acknowledgments

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Optimization of a Chloride-Tolerance Genetic Marker to Develop Improved Soybean Varieties

M.P. da Silva,[1] J.A. Najjar,[2] L.A. Mozzoni,[1] and K.L. Korth[2]

Abstract

Soybean, [*Glycine max* (L.) Merr.], varieties can vary widely in their sensitivity to salts, and especially to chloride in soil and water. Exposure to harmful levels of salt can result in stunted plant growth, reduced yields, and even plant death. In most cultivated soybean, there is one gene that is known to confer tolerance against high levels of chloride found in some irrigation waters and soil. We have optimized a test for the presence of the DNA encoding this gene, generally known as a DNA marker. This marker was shown to be very effective in differentiating between plants with different forms of the chloride-tolerance gene. By testing soybean tissue, even at early plant growth, we can apply these tests to look for the marker in a given plant. This has the potential to make the breeding process much more efficient and faster because we would not have to rely on growing plants to maturity to measure how tolerant they are to salt.

Introduction

High concentrations of chloride and salts in irrigation water and soils can negatively affect the yield potential of many crops. Salt stress in crops is a problem that is increasing in agriculture, and across the entire globe, 7%–8% of all arable land is considered saline (Tanji, 2002). In Arkansas, soils irrigated with groundwater carrying high chloride concentrations can be prone to the buildup of harmful salts. Soybean varieties differ in reactions to salt stress. Those varieties that can partially exclude chloride and other salts from their leaves are more salt-tolerant and are referred to as chloride excluders. Those soybean genotypes that cannot exclude salts from the foliar tissue are salt-sensitive and called chloride includers. Salt tolerance in most soybean is conferred primarily via a single gene, *Glyma03g32900*, designated called either *GmSALT3* (Guan et al., 2014) or GmCHX1 (Qi et al., 2014).

The application of DNA markers has revolutionized plant breeding. By tracking specific genes or simply small bits of DNA, researchers can test for the presence of the desired gene and therefore select desirable individuals from a large, mixed population (Charcosset and Moreau, 2004). Because only very small amounts of tissue are needed, and the test is not dependent on the age of the plant, this technique can be used on plants as young as seedlings, or even on individual seeds. In this work, we have initiated steps to optimize a specific DNA marker to track the gene responsible for soybean plants behaving as either chloride excluders or includers.

Procedures

Individual seeds from 94 soybean lines were germinated and grown in pasteurized river sand. Leaf tissue from 4-week-old plants was removed and tested for the presence of the *GmSalt3* marker called M1, as described by Do et al. (2018). The lines used were selected either as known control plants or because they are at varying stages in the University of Arkansas System Division of Agriculture's Soybean Breeding Program.

Genomic DNA was isolated from leaves of individuals of each soybean line by a modified Cetyl Trimethyl Ammonium Bromide (CTAB) extraction (Wilson, K., 1987) and suspended in TE buffer (10 mM Tris, pH 8.0, 1 mM EDTA). The final DNA concentration was determined via spectrophotometry. A Kompetitive Allelic-Specific PCR (KASP) assay was used on the plant samples to test for single-nucleotide polymorphisms (SNPs) with the M1 marker as described (Do et al., 2018). The KASP reactions were prepared and conducted via methods described by LGC Genomics, LLC (http://www.lgcgroup.com). The marker product was amplified and ultimately measured by levels of fluorescence, which indicate the specific SNP in the DNA sequence.

Results and Discussion

Samples of DNA can be isolated from very small amounts of plant tissue, and then specific sequences, or markers, can

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be amplified relatively quickly. In the case of the KASP assay that we applied here, the amplified sequence can also be differentiated from closely related sequences that might also be present. This technique is sensitive enough to distinguish between two closely related sequences that vary by only a single DNA nucleotide. We assayed 94 individuals that came from populations at varying stages in the breeding program, or that were already known to be chloride excluders or includers.

In the KASP assay, the DNA fragment is amplified through a series of temperature shifts of the total reaction in a small volume of liquid. As the specific fragment is amplified, it can be detected with the use of specific dyes, fluorescein (FAM), or hexachlorofluorescein (HEX) in the reaction that emits fluorescent signals. The signals are measured in the instrument and indicate whether a specific sequence or allele is present. Figure 1 shows the output of this assay and indicates a clear separation of genotypes based on the type of an SNP present in either type of plant. This outcome told us that the marker we used could clearly distinguish between chloride excluders and includers, at least among the samples we tested. Previous work has shown that individual soybean varieties can sometimes have a mixed or intermediate level of chloride tolerance (Cox et al., 2017). Ultimately, this assay could help us determine why some varieties show mixed responses to chloride in the field. Clearly, this marker can differentiate between the chloride excluders and includers that we tested in this set of experiments.

Practical Applications

Optimization of reliable DNA markers is critical to improving the speed and efficiency of plant breeding. The tool described here will help us determine the accuracy of variety designations as chloride includer vs. excluder, and to know the level of salt-tolerance variation within populations. Breeding lines in the Soybean Breeding Program have been regularly screened for chloride uptake and salt sensitivity, and multiple varieties have been released that are chloride excluders for commercial production. Application of tools like this one can help growers have confidence in the labeling of varieties advertised as chloride excluders or includers.

Acknowledgments

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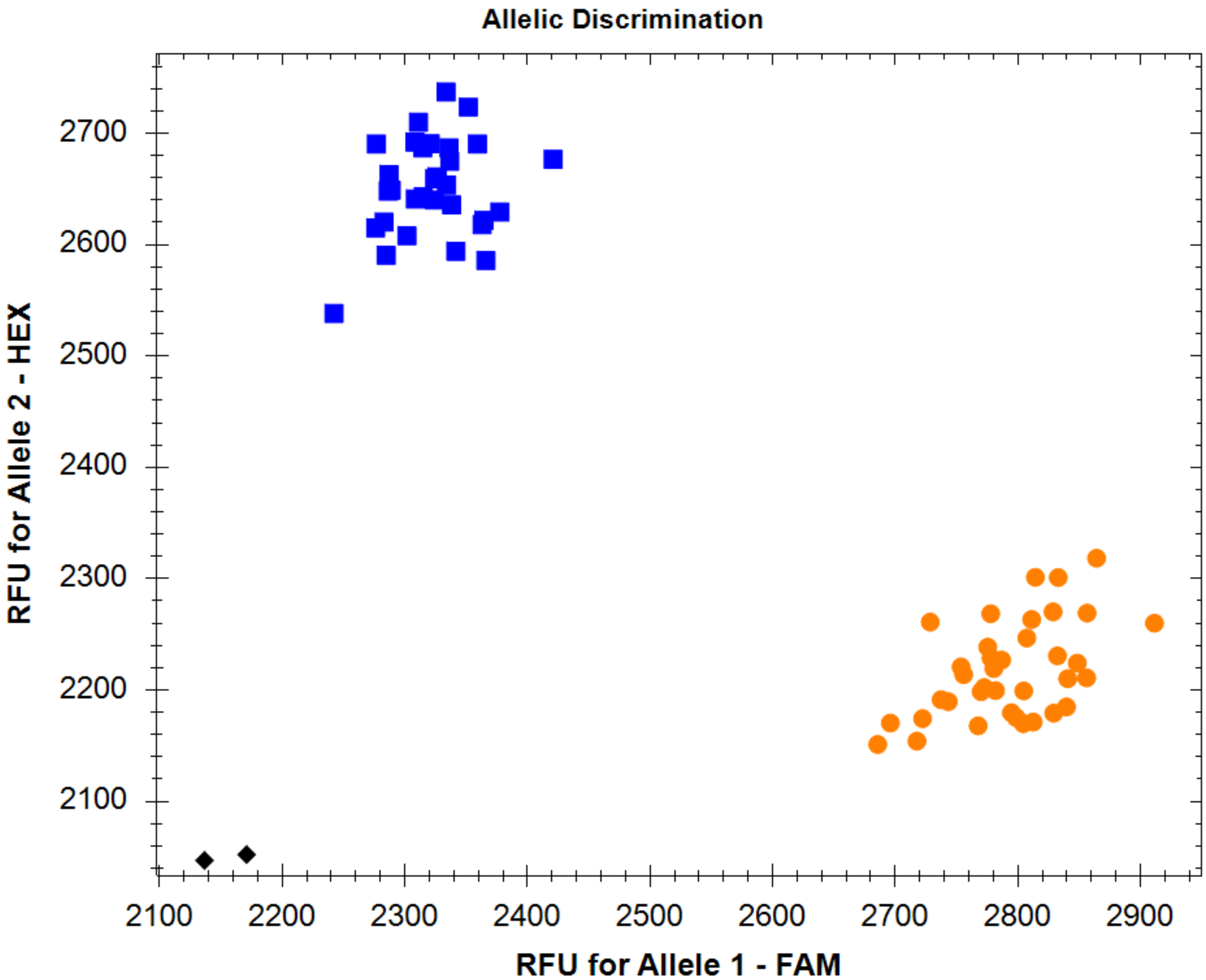

Fig. 1. Genotyping cluster plot with homozygous alleles reported by FAM (*x*-axis) and HEX (*y*-axis), where each data point represents the Relative Fluorescence Units (RFU) signal of a DNA sample taken from an individual plant. Orange circles indicate a signal from salt-tolerant lines, blue squares indicate a signal from salt-sensitive lines, and black diamonds are signals from no-DNA control reactions.

Advances in Soybean Microspore Culture

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Abstract

Doubled haploid (DH) technology provides an advanced breeding tool capable of yielding elite varieties in a rapid timeframe. However, recalcitrance to tissue culture stimuli has limited DH work in many agronomic crops, especially among legumes such as soybean [*Glycine max* (L.) Merr.]. In previous Arkansas Soybean Promotion Board-funded research, Hale et al. (2019) developed a DH protocol for soybean through the culture of isolated microspores (immature pollen). Here, cytological procedures were used to characterize a sequence of development from microspore to advanced embryo. Culture conditions required for advanced embryo development were identified. Also, flow cytometry combined with fluorescent microscopy was used to confirm the haploid status of isolated cells placed into culture and to identify instances of spontaneous chromosome doubling (conversion of haploids to diploids). The present study provides a platform for the investigation of soybean microspore culture and a possible strategy to produce soybean DHs.

Introduction

The goal of this research project was to develop an efficient soybean microspore culture system for diverse genetic applications. The product of this developmental program is referred to commonly as a DH and holds immense value for breeding programs (Wędzony et al., 2009). Among the benefits of DH technology are trait fixation in parental lines, the discovery of recessive phenotypes, and savings in time and cost in cultivar development (Dunwell, 2010; Garda et al., 2020). Also, DH provides a framework for the study of stress-induced histodifferentiation and cell cycle regulation (Touraev et al., 1997). This system, based on the isolation and culture of microspores, is intended to be used to obtain haploid plants and/or doubled haploid plants of microspore origin.

Complementary research identified several factors that stimulate an embryogenic response in soybean microspore cultures (Garda et al., 2020), including the use of 10 ppm 2,4-dichlorophenoxyacetic acid (2,4-D) as auxin. In order to advance the existing soybean DH platform, this project proposed to optimize the isolated microspore culture system for the following parameters: 1) sustained cell division, 2) status of chromosome doubling, 3) embryo formation, and 4) embryo conversion to plants. Sustained cell division from 100% of soybean microspore cultures was achieved by Hale et al. (2019), with the addition of 0.1 ppm N^6-benzyladenine (BA) as cytokinin. The observation of sustained cell division from soybean microspores had not been reported in the literature previously. Hale et al. (2019) presented preliminary results for chromosome doubling and embryo formation, which are updated with current progress in the present paper. Continuing emphasis will be placed on embryo maturation and conversion to plants in future endeavors.

Procedures

The genotype IAS-5 was utilized for all experiments, with confirming observations using genotypes Maverick and Williams82. Seeds were grown on germination paper in a Conviron (Winnipeg, Canada) growth chamber for three days in dark, moist conditions before being transplanted into Miracle-Gro Moisture Control potting medium. Growth chamber settings were 82 °F continuous, 16 hours/daylight at 10,000–15,000 lux, 90% relative humidity.

Donor plants were subjected to pretreatment temperature shock as floral buds reached 0.16 in. (2-5 days before anthesis). Plants were moved to a Conviron growth chamber at 50 °F day/46 °F night for 3 days. On the 4th day, donor plants were moved to a refrigerator at 39 °F and kept overnight in the dark. Microspore isolation took place the following day.

Floral buds meeting developmental criteria (360 total) were selected for dissection. Buds were surface sterilized in a 20% bleach solution for 7.5 minutes followed by 3 rinses with

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sterile water for five minutes each. Androecia were dissected from the buds using a Zeiss™ (Jena, Germany) Stemi 2000-C Stereo Microscope and anthers placed in a 0.4 M mannitol solution containing 2% sucrose and 2% sorbitol. Once in solution, the anthers were crushed with a glass rod to encourage the release of microspores. Remaining somatic tissue was removed from the culture with 0.0024- and 0.0016-in. vacuum-driven infiltration systems, followed by filtration with a 0.0016-in. cell strainer. The resulting microspore solution was centrifuged for 6 minutes at 2000 RPM. The supernatant was discarded, and pelleted microspores were resuspended in an induction medium.

Microspores were cultured in sterile BNN induction medium (Hale et al., 2019; Garda et al., 2020). In order to promote cell proliferation, a gradient of 2,4-D was tested independently and in combination with α-naphthaleneacetic acid (NAA). Picloram (PIC) was used on occasion as an auxin source. The use of BA was maintained across the media to promote the development of induced microspores (Hale et al., 2019). Phytohormone levels and the corresponding development of embryogenic masses are summarized in Table 1.

Induction media also were supplemented with sucrose (2%) and sorbitol (2%) as an osmoticum. Tests with abscisic acid (ABA) and coconut water (CW) were performed, as were direct comparisons between BNN (Garda et al., 2020) and NLN (Lichter, 1982) basal media. Supplemental BABI transfer medium (Greenway et al., 2012) plus 0.35 ppm BA and 0.006 ppm PIC was added later in culture for all experiments.

Following microspore dissection and resuspension in media, cultures underwent an initial 3-day dark incubation at 51.8 °F in an Innova shaker followed by the addition of low light at 64.4 °F in a Conviron growth chamber during days 4–7. One-week old cultures were moved to 77 °F with maintained light intensity.

Induction media were evaluated for their ability to support embryogenic growth. A Zeiss™ Primovert inverted microscope equipped with ZEN Imaging software (v.2.3 [blue edition]) was used to evaluate structure development at 7-day intervals for 8 weeks. Embryogenic masses were quantified after 14 days of culture.

In preparation for flow cytometry, freshly isolated cultures were incubated in protoplast enzyme solution for 16 hours at 82.4 °F to minimize autofluorescence signal. Microspores were filtered through a 0.0024-in. vacuum-driven infiltration system, rinsed and fixed in chilled 70% ethanol for 12–14 hours. Fixation was followed by nuclei staining with a 5 ppm 4′6-diamidino-2-phenylindole (DAPI) solution.

Mesophyll cells and unstained microspore cultures were used as internal standards for flow cytometry. Leaf tissue (20 mg) was frozen and chopped in the protoplast enzyme solution. After incubation, isolated cells were filtered through 0.0039- and 0.0024-in. vacuum-driven infiltration systems and processed alongside microspore samples. The unstained standard followed the sample preparation protocol, excluding the DAPI immersion step.

A BD FACSCalibur flow cytometer (Franklin Lakes, N.J.) was used to assess ploidy, cell size, and cell granularity. The DAPI solution was excited with a Trigon ultraviolet laser and emission collected with a bandpass filter for 10,000 nuclei events. FACS Diva software (v. 6.0) software was used for ploidy analysis.

The cytological analysis was performed with fixed microspore samples. Aniline blue (AB) (Sigma-Aldrich CAS #28631-66-5) was used to detect callose deposition within the membrane of microspores. Samples were first counterstained with a 10 ppm propidium iodide (PI) solution (Sigma-Aldrich Cas # 25535-16-4) for 10 minutes. After washing, samples were stained with 0.1% AB for 20 minutes and then rinsed thrice before observation. Fluorescent microscopy was performed with a BioTek Lionheart FX (Atlanta, Ga.).

Experiments consisted of at least 3 repetitions with 3 or more replicates per treatment, and the results were reported as mean ± standard error of the mean (SEM). Data were collected and preprocessed in Microsoft Excel (v. 16.0). Statistical significance ($P < 0.05$) was determined using a one-way analysis of variance (ANOVA). If significance between multiple independent treatments was observed, the mean separation was calculated using Tukey's honestly significant difference (HSD) test at $\alpha = 0.05$.

Results and Discussion

Ploidy analysis of freshly isolated cells revealed a predominant peak with half the fluorescence intensity of the leaf nuclei standard, confirming the haploid nature of the microspores placed into culture (Fig. 1 b–c). Ground truthing via fluorescent microscopy validated the flow analysis, with the targeted microspore developmental stage (late uninucleate) comprising 84% of the total cell population (data not shown).

Flow cytometry had limited utility in monitoring embryogenesis in the absence of plantlet regeneration, as the instrument was incapable of distinguishing between bicellular microspores and those that had undergone spontaneous chromosome doubling (e.g., by nuclear fusion). Microscopy did reveal an inconsistent population of stressed microspores with a large, brightly stained nucleus resembling previous reports of nuclear fusion in soybean (Cardoso et al., 2004; Hale et al., 2019) and barley (*Hordeum vulgare* L.) (Kasha et al., 2001) (Fig. 1f). Because spontaneous chromosome doubling was inconsistent, the use of anti-mitotic agents should be explored in conjunction with the microspore culture system to promote the direct regeneration of DH plants.

The first sign of embryogenesis was the fragmentation of the microspore vacuole and the presence of a cytoplasmic pocket (Fig. 2d). Shrinkage of the vacuole followed, as did the accumulation of starch along the outside of the microspore (Fig. 2e). By day 6, the internal reorganization of embryogenic microspores was distinguishable from those developing into normal pollen, which was rich in starch (Fig. 2c).

Between days 7 and 10, reprogrammed microspores enlarged and underwent membrane rupture at one or more germ pores (Fig. 2f). A globular, rough-surfaced pro-embryo developed from the breakage point (Fig. 2g). Distinct regions of callose deposition (microspore) and nucleic acid (pro-embryo) were observed (Fig. 3d), as was cytoplasmic streaming between the two structures (Fig. 2g).

Day 11 through day 14 of culture was characterized by rapid cell division in which pro-embryos developed into callus-like masses lacking meristem identity (Fig. 2h). Most structures arrested at this stage; however, a few developed into large, heart-shaped embryos with bilateral symmetry (Fig. 2i). All embryos entered developmental arrest under these culture conditions.

Phytohormone gradients were evaluated in a BNN background (Table 1). Primarily, the rate of cell division increased with higher concentrations of auxin. 2,4-D was the most productive of the auxins tested, while intermediate levels of PIC were also adequate for the induction of embryogenesis. The use of ABA appeared to improve cell division during the first week of culture while noticeably reducing mortality (data not shown); however, its effectiveness lessened during week 2 as viable microspores became acclimated to stable culture conditions. Preliminary evidence suggests that CW and NLN are both promotive of advanced embryo development, although further work is needed to achieve statistical power. Continuing work is focused on obtaining more advanced stages of embryo development as a means to achieve conversion into plants.

Practical Applications

Although technological advances have increased crop yield throughout the 21st century, the challenge to stabilize food security with less arable land is becoming an increasingly daunting task. With a population expected to exceed 9 billion before 2050, complicated by climate variability, it is prudent to continue the optimization of crop plants such as soybean (Lutz et al., 2001).

The application of DH technology provides a breeding tool capable of increasing yield to meet the grower and consumer demands. Plants recovered from DH platforms are true-breeding lines in one step, with all traits fixed, as opposed to 6–7 generations of inbreeding to fix traits conventionally (Ferrie and Caswell, 2011). As a result, a functional soybean DH protocol would drastically reduce the time and cost required to develop new cultivars, resulting in increased economic yield for growers.

Acknowledgments

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Table 1. Phytohormone composition in induction medium and corresponding microspore proliferation into embryogenic masses.

Name	2,4-D[a]	BA[a]	NAA[a]	ABA[a]	PIC[a]	Mean no. of embryogenic masses/mL[b]
	------------------------------- ppm	-----------------------------------				
BNN1	—	0.1	—	—	0.06	11.00 ± 1.66
BNN2	—	0.1	—	—	0.6	7.20 ± 1.34
BNN3	0.05	0.1	—	—	—	7.20 ± 1.34
BNN4	0.25	0.1	0.2	—	—	8.00 ± 1.89
BNN5	0.25	0.1	2	—	—	9.33 ± 2.24
BNN6	0.5	0.1	—	—	—	8.00 ± 1.62
BNN7	5	0.1	—	—	—	7.33 ± 0.92
BNN8	5	0.1	—	0.03	—	9.33 ± 1.09
BNN9	5	0.1	—	0.1	—	9.78 ± 1.11
BNN10	10	0.1	—	—	—	10.29 ± 1.37
BNN11	20	0.1	—	—	—	10.29 ± 1.78
BNN12	40	0.1	—	—	—	11.20 ± 2.09

[a] 2,4-D = 2,4-dichlorophenoxyacetic acid; BA = N^6-benzyladenine; NAA = α-naphthaleneacetic acid; ABA = abscisic acid; PIC = Picloram.

[b] Mean value ± standard error of approximately 7 repetitions.

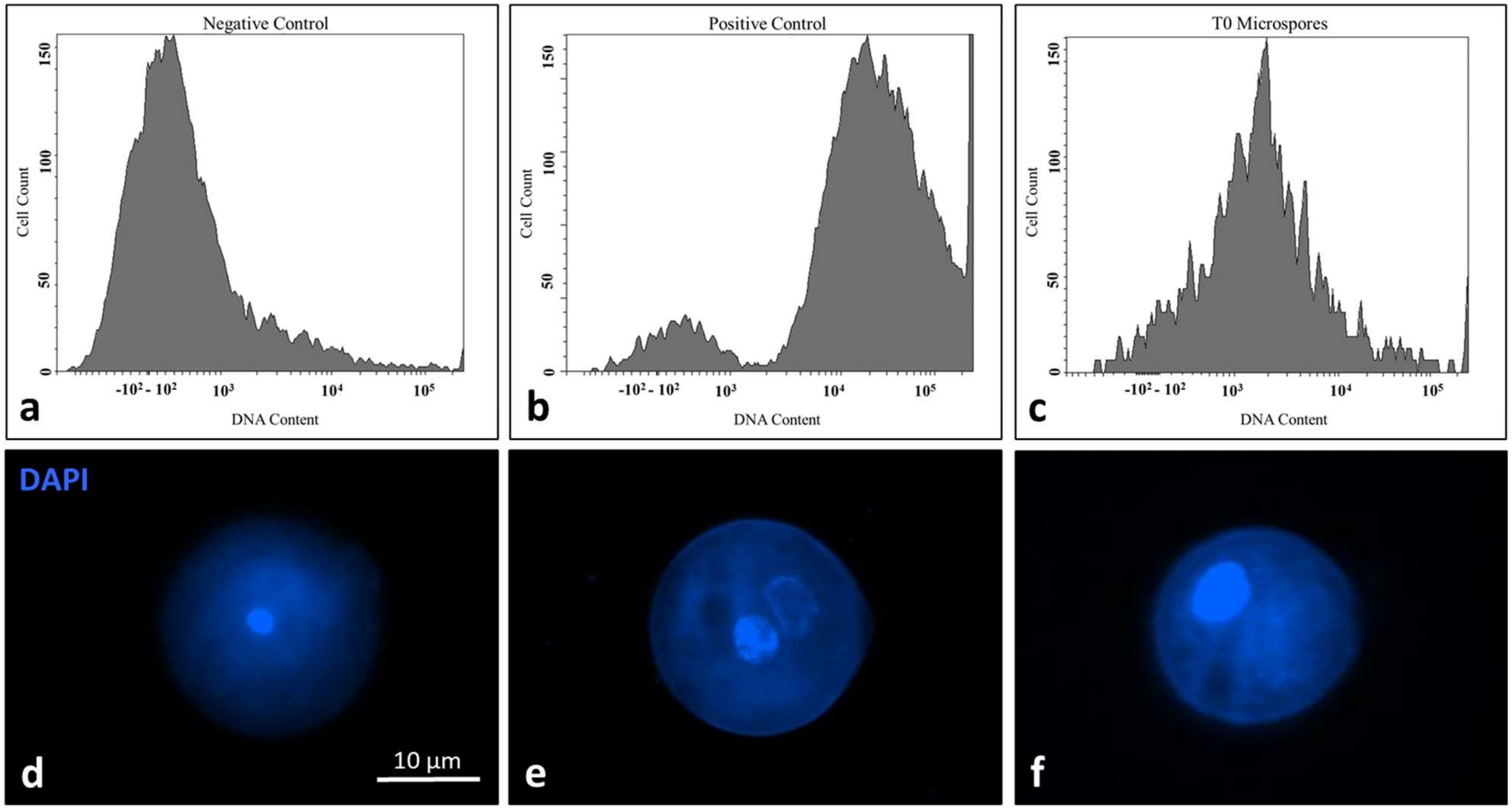

Fig. 1. (a-c) Ploidy analysis of freshly isolated microspores. (a) Negative control comprised of unstained microspores; (b) Diploid control derived from leaf tissue nuclei; (c) Freshly isolated microspores demonstrating half the fluorescence intensity as the leaf tissue standard. (d-e) Cytological implication of spontaneous diploidization via nuclear fusion. (d) Vacuolated unicellular microspore with a central nucleus; (e) Bicellular microspore which has undergone an asymmetrical pollen mitosis 1 division; (f) Microspore with a brightly-stained, acentric nucleus distinguishably larger than that of unicellular microspores, likely the result of nuclear fusion. d-f bars = 10 µm (0.00039 in.).

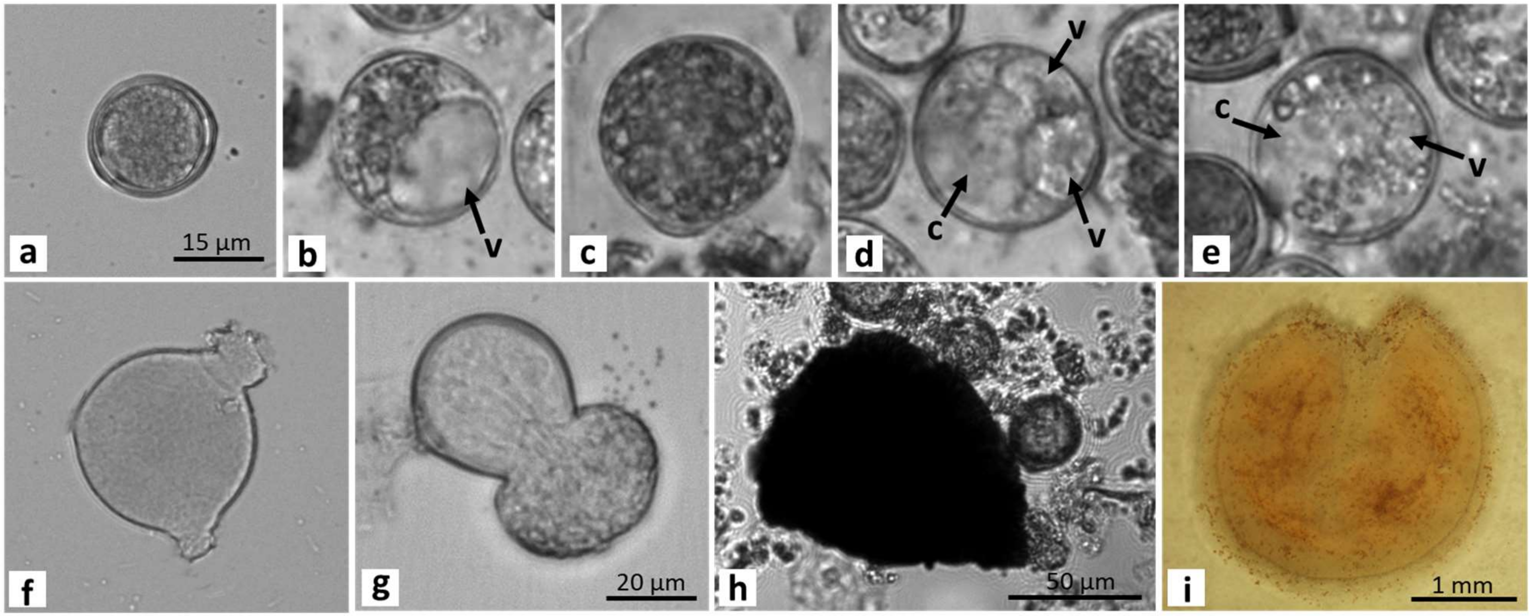

Fig. 2. Proposed developmental stages of soybean microspore embryogenesis. (a) Early unicellular microspore; (b) Vacuolated unicellular microspore; (c) Mature pollen grain; dark, granular material corresponds to starch; (d) Embryogenic microspore which had undergone vacuolar fragmentation (v); this developmental stage was also characterized by an acentric cytoplasmic pocket (c); (e) Advanced embryogenic microspore with a shrunken vacuole against the cell periphery; at this stage, granular material was also observed along regions of the pollen wall; (f) Enlarged microspore herniating through two of three apertures; (g) Early pro-embryo developing from the exine rupture site; (h) Embryogenic mass after approximately two weeks in culture; (i) Heart-shaped embryo at day 23 of culture. a-f bars = 15 µm; g = 20 µm; h = 50 µm; i = 1 mm (0.00059, 0.00079, 0.002, and 0.039 in., respectively).

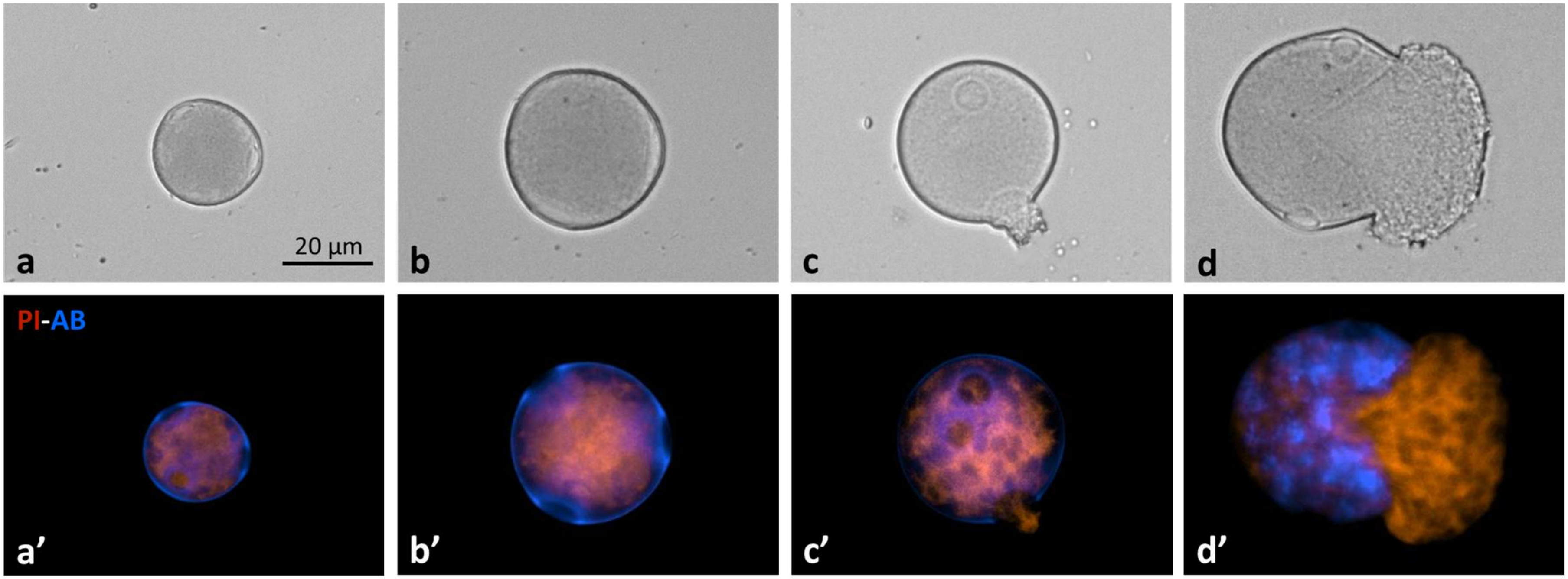

Fig. 3. Cytological analysis of soybean microspore development into haploid pro-embryo. (a-d) Brightfield images; (a'-d') Aniline Blue (AB) was used to detect callose (cell wall material), and Propidium Iodide (PI) was used to detect nucleic acids (DNA and RNA) in the same tissues. (a,a') Microspore prior to vacuolation; (b,b') Enlarged, vacuolated microspore; (c,c') Induced microspore breaking the exine at an aperture site; (d,d') Pro-embryo development with regions of callose deposition (microspore) and nucleic acids (emerging globular structure). (a-d') bar = 20 µm (0.00079 in.).

Efficacy of Chitosan-Based Products to Manage Southern Root-Knot Nematode in Arkansas

T. R. Faske,[1] K. Brown,[1] and M. Emerson[1]

Abstract

Two chitosan-based products, Nemasan and OII-YS™, were evaluated for suppression of southern root-knot nematode, *Meloidogyne incognita*, in the field and greenhouse. Suppression of nematode infection and subsequent grain yield protection by seed-applied chitosan and that applied as a broadcast spray (at planting) was similar to that of the non-treated control in the field. Furthermore, the nematode counts at the end of the season were similar among treatments, suggesting that chitosan had little or no impact on nematode infection or population densities. Similar results were observed with fluopyram-treated seed in the field. In the greenhouse study, suppression of root-knot nematode galling was similar between seed-applied chitosan and the non-treated control, while there was a trend in the suppression of nematode reproduction with fluopyram. These data indicate that applications of chitosan-based products provide little suppression of nematode infection and yield protection on soybean in a field with a severe damage threshold (>300 nematodes/100cm^3 soil at harvest) of southern root-knot nematode.

Introduction

Soil organic amendments, such as manure, compost, and chitin have been evaluated to manage insects, pathogens, and nematodes in row crop agriculture (Duncan, 1991; Sharp, 2013). Chitin is a polysaccharide and the primary makeup of fungal cell walls, insect and crustacean exoskeletons, but only a small amount is found in the middle layer of nematode eggs. Though chitin-based materials have been reported to suppress plant-parasitic nematode when high rates are used (tons/ac), it is unclear how these products work (Mian et al., 1982; Godoy et al., 1983; Culbreth et al., 1986; Westerdahl et al., 1992). Some studies indicate that chitin promotes the growth of beneficial chitiniolytic fungi that parasitize nematode eggs, while others suggest that as chitin breaks down in the soil it releases nematicidal levels of ammonia (Duncan, 1991).

Despite some success in suppressing plant-parasitic nematodes with crustacean chitin flakes, very few commercial products have been developed. One commercial product, ClandoSan® (Ingene Biotechnology, Inc., Columbia, Md.) that contains chitin and urea was reported to provide some suppression of root-knot nematodes (Rodriguez-Kabana et al., 1990; Westerdahl et al., 1992). Recently, two products with a similar ingredient, chitosan, are being marketed for use in agriculture. Chitosan is a linear polysaccharide produced by the deacetylation of chitin. Nemasan (Organisan Corporation, Carrollton, Ga.), a mixture of quillaja extract (8.0%) and chitosan (2.0%), was registered in 2018 as a bionematicide in row crop agriculture, vegetables, ornamentals, and turfgrass. Aqueous extract from *Quillaja saponaria* (soap bark tree found in Chile) has been reported to have some toxicity against plant-parasitic nematodes in the lab trials (San Martin and Magunacelaya, 2005). The second product, OII-YS™ (Oraganisan Corporation), a mixture (8.0%) of chitosan and Yucca extract, is marketed as a natural adjuvant rather than a nematicide. Currently, the efficacy of chitosan-based products to suppress root-knot nematodes in soybean is unknown. Thus, the objectives of this study were to assess the efficacy of chitosan to suppress southern root-knot nematode infection and reproduction on soybean.

Procedures

The efficacy of chitosan to suppress southern root-knot nematode was evaluated in a soybean field with a history of the nematode near Kerr, Ark. The 2018 and 2019 site had a moderate population density of root-knot nematode at planting at 64 and 113/100 cm^3 soil, respectively. The previous crop in both years was corn. Based on the web soil survey, the soil series for the 2018 field was a Keo silt loam, but based on soil texture analysis it was a sandy loam (58% sand, 40% silt, and 2% clay, and < 1% organic matter (OM)). Similarly, the 2019 field soil series was a Rilla silt loam, but lab analysis

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classified it as a sandy loam (47% sand, 47% silt, 6% clay, and <1% OM).

Cultures of *Meloidogyne incognita* race 3 (Kofoid and White), Chitwood (isolate 'Black Oak') were maintained on tomato (*Solanum lycopersicum* L., 'Rutgers'). Eggs were extracted from roots with 0.5% NaOCl and used as inoculum in the greenhouse study.

Replicated Field Experiments. The southern root-knot nematode susceptible cultivars, Delta Grow DG 4970 GLY and DG 4880 GLY were used in 2018 and 2019, respectively. The two chitosan applications were a broadcast spray at planting and a seed treatment. Nemasan (1 pt/ac) + OII-YS™ (1 pt/ac) were broadcast through flat-fan nozzles (Tee-Jet 110015VS) spaced 30-in. on 2 center rows using a backpack sprayer. The sprayer was calibrated to deliver 20 gal/ac. Per the manufacturer's recommendation, the spray mix pH was adjusted to below 5.0 before adding OIIYS™ and Nemasan. Seed-applied OII-YS™ at a rate of 2.0 fl oz/cwt (personal communication with manufacturer) and seed-applied fluopyram (ILeVO® 600 FS, BASF Corporation, Florham Park, N.J.) at a rate of 1.2 fl oz/cwt (0.15 mg ai/seed) were applied with a rotary seed treating system (UNICOAT 1200 CCS, Universal Coating Systems, Inc., Independence, Ore.). No other pesticides were used on the seed, and non-pesticide treated seed was used as the control.

Cultivars were planted on 29 May 2018, and 28 May 2019, at a seeding rate of 150,000 seed/ac. Weeds were controlled in plots based on recommendations by the University of Arkansas System Division of Agriculture's Cooperative Extension Service (Barber et al., 2019). These experiments were furrow irrigated, and within 30 days after planting received a total of 2.61 and 5.47 in. of rainfall in 2018 and 2019, respectively. Plots were 4 rows wide, 30-ft-long, with 30-in. row spacing, separated by a 5-ft fallow alley. Treatments were arranged in a randomized complete block design with 4 replications. Seedling vigor, phytotoxicity, and stand counts were evaluated approximately 30 days after planting (DAP). Vigor was based on a 1-5 scale with 5 being the best, and stand count was recorded as seedlings per 10 ft of row. Soil samples were collected within each block at planting and each treatment at harvest. Soil samples were a composite of a minimum of 10 soil cores taken 8 to 10 in. deep with a 0.75-in.-diam soil probe. Vermiform nematodes were collected with a Baermann ring system and enumerated using a stereoscope. To determine nematode infection, 10 roots were arbitrarily sampled 50–60 DAP from non-harvest rows from each plot. Gall rating was based on the percentage of root system galled. The center two rows of each plot were harvest on 2 October 2018, and 5 November 2019, with a K Gleaner combine equipped with a HarvestMaster™ Single BDS HiCap HM800 Weigh System.

Replicated Greenhouse Experiments. In the greenhouse experiment, pasteurized, coarse-textured sand was filled in D4-HO Deepot™ (Stewe and Sons, Tangent, Ore.). Fluopyram, OII-YS™, and non-treated seed treatments from the 2018 field experiment were used. Seeds were planted at 0.75 in. deep and approximately 3,400 eggs of *M. incognita* in 2 mL of water were dispersed into three 2-in. deep holes around each seed. Roots were sampled at 42 DAP, blotted dry, and weighed. The percent of root system galled was assessed for each root system. Eggs were extracted with 1.0% NaOCl and enumerated with a stereomicroscope. Treatments were arranged in a randomized complete block design with six replications per treatment, and the experiment was conducted twice.

Data were subject to ANOVA using IBM SPSS Statistics 25.0 (International Business Machines Corp., Armonk, N.Y.) with year and treatment as fixed variables and replication as a random variable. Percent root system galled data were arsine transformed [arcsine(square root(x + 0.5)] to normalize for analysis and non-transformed data are reported. The differences in this paper were significant at $P \leq 0.05$.

Results and Discussion

There was no ($P > 0.05$) year (cultivar) by nematicide treatment interaction for root galling, final nematode population density, or yield in the field study; thus only the main effects are reported (Table 1). Stand counts and seedling vigor ratings were similar among seed-applied nematicides, so none had a negative effect on seedling emergence (data not reported). Phytotoxicity as necrotic rings on cotyledons was observed from fluopyram-treated seed only. No effect of treatment was observed for percent root system galled, final nematode population density, or yield (Table 1). There was a difference ($P \leq 0.01$) in the final nematode population density between years, which was due to soil samples being collected six weeks after plants prematurely died. Premature plant death in 2018 was a result of more severe root galling and drought-like conditions during grain fill (June and July).

There was no ($P > 0.05$) treatment by experiment replication interaction for percent root system galled or nematode reproduction in the greenhouse study; thus only main effects are reported (Table 2). No differences among treatments were observed for percent of root system galled or reproduction, but there was a trend of reduced nematode reproduction by fluopyram-treated seed.

Chitosan applied as a broadcast spray or seed treatment had little impact on nematode galling, final nematode population density, or grain yield protection. Chitin-based products have been reported to suppress root-knot nematodes on vegetable crops in the greenhouse or field (Mian et al., 1982; Godoy et al., 1983; Culbreth et al., 1986; Rodriguez-Kabana et al., 1990; Westerdahl et al., 1992). However, in those studies, chitin was incorporated into the soil for 2 to 10 wk prior to planting. If the release of ammonia is the mode of action, then incorporating and allowing several days for chitin or chitosan to affect nematode survival and reproduction may be important. Clearly, application as a broadcast spray at planting or applied on the seed was ineffective at suppressing root-knot nematode on soybean.

Practical Applications

Soil amendments such as chitosan-based materials are being marketed as an alternative approach to nematode control. In this study, the benefit of chitosan-based materials, specifically Nemasan and OII-YSTM were ineffective in the suppression of the southern root-knot nematode on soybean.

Acknowledgments

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Table 1. Field performance of chitosan-based bionematicide in a southern root-knot nematode infested field.

	Percent root system galled†	Final nematode population density‡	Yield§
	%	nematode/100cm^3 soil	bu./ac
Year, cultivar			
2018, Delta Grow DG 4970 GLY	42.1	434 a	22.7
2019, Delta Grow DG 4880 GLY	25.0	860 b	32.7
Nematicide treatment and rate			
Non-treated control	32.7	746	27.1
Nemasan (1 pt/ac) + OII-YS™ (1 pt/ac) - broadcast	34.4	650	25.8
OII-YS™ (2.0 fl oz/cwt)	37.0	496	28.7
ILeVO® (1.2 fl oz/cwt or 0.15 mg ai/seed)	33.9	698	29.3
Statistics: *P* > F			
Year	0.08	0.01	0.07
Treatment	0.23	0.43	0.50
Year x Treatment	0.86	0.36	0.48

† Percent of root system galled at 50 and 60 days after planting in 2018 and 2019, respectively.
‡ Final nematode population density from soil samples collected near harvest.
§ Adjusted to 13% moisture.

Table 2. Suppression of southern root-knot nematode infection and reproduction in response to seed-applied chitosan in a greenhouse study.

Nematicide treatment and rate	Percent root system galled†	Eggs per gram of root
	%	
Non-treated control	22.5	12,155
OII-YS™ (2.0 fl oz/cwt)	19.3	11,275
ILEVO® (1.2 fl oz/cwt or 0.15 mg ai/seed)	12.3	4,505
P > F	0.25	0.09

† Percent of root system galled at 42 days after planting.

Field Efficacy of Four Seed-Applied Nematicides on Two Soybean Cultivars (Maturity Group 4 and 5) to Manage Southern Root-Knot Nematode in Arkansas

T. R. Faske,[1] and M. Emerson[1]

Abstract

Four seed-applied nematicides (Avicta®, ILEVO®, Votivo®, and Nema Strike™) were evaluated in 2019 on two southern root-knot nematode susceptible cultivars, Asgrow AG 46X6 RR2X and AG 52X9 RR2X/SR, in a field trial. Based on the percent of root system galled, there was no effect of seed-applied nematicides on the suppression of nematode infection 62 days after planting on either of the cultivars. However, these seed-applied nematicides did provide an average numeric yield protection of 3.1 and 4.4 bu./ac compared to the non-treated control on AG 46X6 and AG 52X9, respectively. Grain yield protection was significantly greater across nematicide treatments on the maturity group (MG) 5 compared to the MG 4 cultivar, with a difference of 5.0 bu./ac. Based on soil samples collected at harvest, the damage threshold by southern root-knot nematode on soybean was severe [5,357 J2/pt soil (1,432 J2/100cm^3 soil)]. These data support the similarities among seed-applied nematicides in root and yield protection and suggest a greater yield benefit with MG 5 soybean cultivars compared to MG 4 cultivars in a southern root-knot nematode infested field.

Introduction

The southern root-knot nematode, *Meloidogyne incognita* (Kofoid and White) Chitwood, is among the most important plant-parasitic nematode that affects soybean production in the Southern United States. It has been reported in nearly every soybean-producing county in Arkansas, and yield losses greater than 75% have been reported on susceptible soybean cultivars (Emerson et al., 2018; Kirkpatrick and Sullivan, 2018). According to the Southern Soybean Disease Workers, the average yield loss estimates due to the southern root-knot nematode in 2018 was 4.0% or 5.6 million bushels of grain in Arkansas and 1.0% or 8.6 million bushels of grain across the South (Allen et al., 2020).

Over the past 15 years, seed-applied nematicides have gained popularity as one of the most commonly used application methods for nematicides in row crop agriculture. They are convenient to use and deliver the nematicide in close proximity to the developing root system. Though a few soybean cultivars are moderately resistant against the southern root-knot nematode (Emerson et al., 2018; Emerson et al., 2019), they are often underutilized because resistance may not exist for a specific herbicide technology or maturity group. As a casual observation, the maturity group (MG) 5 often yields better than MG 4 in southern root-knot infested fields (Emerson et al., 2018; Emerson et al., 2019); however, further studies are needed to investigate these observations. Thus, the objective of this study was to evaluate the field efficacy of four seed-applied nematicides on root and yield protection of an *M. incognita*-susceptible MG 4 and MG 5 soybean cultivar.

Procedures

The field efficacy of four seed-applied nematicides was evaluated in a soybean production field with a history of southern root-knot nematode near Kerr, Ark. The site had a low population density of root-knot nematode [175 J2/pt soil (37/100 cm^3 soil)] at planting that was previously cropped in corn. Based on the web soil survey, the soil series was a Rilla silt loam, but lab analysis classified it as a sandy loam (47% sand, 47% silt, 6% clay, and <1% organic matter).

Two soybean cultivars, Asgrow AG 46X6 RR2X (2,530 seeds/lb) and AG 52X9 RR2X/SR (3,300 seed/lb) (Asgrow Seed Co. LLC, Creve Coeur, Mo.) that were rated as susceptible and very susceptible, respectively, to the southern root-knot nematode were used (Ross et al., 2020). All insecticides and nematicides were applied with a rotary seed treating system (UNICOAT 1200 CCS, Universal Coating Systems, Inc., Independence, Ore.). A base fungicide of Trilex® 2000 (trifloxystrobin + metalaxyl, Bayer CropScience, Research Triangle Park, N.C.) at 1.0 fl oz/cwt + insecticide treatment of Gaucho® 600 F (imidacloprid, Bayer CropScience) at 1.7 fl oz/cwt (0.12 mg ai/seed) was used as the non-treated control and base treatment for most of the nematicides. Nematicide treatments included: Avicta® 500 FS (abamectin, Syngenta Crop Protection, Greensboro, N.C.) at 2.6 fl oz/cwt (0.15 mg ai/

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seed) + Cruiser Maxx® Vibrance® 2.49 FS (thiamethoxam, + mefenoxam + fludioxonil + sedaxane, Syngenta Crop Protection) at 3.22 fl oz/cwt; ILEVO® 600 FS (fluopyram; BASF Corporation, Florham Park, N.J.) at 1.2 fl oz/cwt (0.15 mg ai/seed) + Trilex® 2000 + Gaucho® 600 F; Poncho®/Votivo® (clothianidin + *Bacillus firmus* I-1582, BASF Corporation) at 1.02 fl oz/140k seed (0.13 mg ai/seed) + Trilex® 2000; and NemaS-Trike™ ST (tioxazafen, Monsanto ST, Monsanto Company, St. Louis, Mo.) at 2.2 fl oz/140k seed (0.25 mg ai/seed) + Trilex® 2000 + Gaucho® 600 F.

Cultivars were planted on 28 May at a seeding rate of 150,000 seed/ac. Weeds were controlled in plots based on recommendations by the University of Arkansas System Division of Agriculture's Cooperative Extension Service (Barber et al., 2019). This study was furrow irrigated. The experimental design consisted of 4 row, 30-ft-long plots, with 30-in. row spacing, separated by a 5-ft fallow alley. Treatments were arranged in a randomized split-plot design with nematicide treatment as the main plot and soybean cultivar as the subplot. Each cultivar by treatment combination was replicated four times. Seedling vigor, phytotoxicity counts were assessed on 13 June, 10 days after planting (DAP). Vigor was based on a 1-5 scale with 5 = best. Soil samples were collected within each block at planting and at harvest. Soil samples were a composite of a minimum of 10 soil cores taken 8 to 10 in. deep with a 0.75-in.-diam soil probe. Nematodes were collected with a Baermann ring system and enumerated using a stereoscope. To determine nematode infection, 10 roots were arbitrarily sampled from rows one and four on 29 July (62 DAP) from each plot. Gall ratings were based on the percentage of root system galled. The center two rows of each plot were harvest on 4 Nov. with a K Gleaner combine equipped with a HarvestMasterTM Single BDS HiCap HM800 Weigh System.

Data were subject to ANOVA using IBM SPSS 25.0 (International Business Machines Corp., Armonk, N.Y.). Percent root system galled data were arsine transformed [arcsine(square root(x)] to normalize for analysis, and non-transformed data are reported. Means, when appropriate, were separated according to Tukey's Honestly Significant Difference (HSD) test at $\alpha = 0.05$.

Results and Discussion

There was no effect of nematicide or cultivar on seedling vigor or population density. Only those seed treated with ILEVO expressed any phytotoxicity. Phytotoxicity was a narrow to wide necrotic ring along the edge of the cotyledonary leaves on 80-90% of seedling per plot. There was no interaction (P = 0.09) between cultivar and nematicide for percent of root system galled (Table 1). Overall, Votivo® and NemaStrike™ had a greater ($P \leq 0.05$) percent root system galled across cultivars compared to the non-treated control. The percent root system galled was similar between cultivars across nematicides, with an average of 5.5%.

There was no interaction (P = 0.88) between cultivars and nematicide for grain yield. Numerically, Avicta® contributed to the greatest grain yield across cultivars. The later maturity group cultivar, AG 52X9, had a greater (P = 0.02) grain yield across nematicides compared to AG 46X6, which was a difference of 5.0 bu./ac or 17%. Phytotoxicity observed on seed treated with ILEVO had no impact on grain yield. The low average grain yield for both cultivars was expected, as the southern root-knot nematode damage threshold was severe [5,357 J2/pt soil (1,432 J2/100cm^3 soil) at harvest].

These data suggest an MG 5 soybean cultivar may perform better than an MG 4 soybean in a field with southern root-knot nematodes. In the 2019 Arkansas soybean performance test, AG 46X6 averaged 65.9 bu./ac and AG 52X9 averaged 64.9 bu./ac across five locations; however, AG 46X6 had a greater yield in only 3 of 7 irrigated locations (Carlin et al., 2019). In this study, grain yield for AG 52X9 was 33.8 bu./ac compared to 28.8 bu./ac for AG 46X6. Seed-applied nematicides contributed to a greater percent of root system galled on both cultivars; however, all nematicides contributed to at least a numeric protection in yield potential. On average, yield protection by nematicides on AG 46X6 was 3.1 bu./ac with a range of 0.1 to 5.6, while on AG 52X9 was 4.4 bu./ac with a range of 3.3 to 5.6.

Practical Applications

Seed-applied nematicides are among the most commonly used nematicides on soybean in Arkansas and the Mid-South. The benefit in root and yield protection among these four seed-applied nematicides was similar. These data suggest a greater yield benefit with MG 5 soybean cultivars compared to MG 4 cultivars in a southern root-knot nematode field.

Acknowledgments

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Table 1. Field performance of 4 seed-applied nematicides on 2 soybean cultivars in a southern root-knot nematode infested field.

	Percent root galling†	Yield‡
Cultivar	**%**	**bu./ac**
Asgrow AG 46X6 RR2X	5.0	28.8 a
Asgrow AG 52X9 RR2X/SR	6.0	33.8 b
Nematicide treatment and rate		
Non-treated control	4.0 a§	28.6
Avicta® 500 FS (0.15 mg ai/seed)	4.6 ab	32.7
ILEVO® 600 FS (0.15 mg ai/seed)	4.7 ab	32.9
Poncho®/Votivo® (0.13 mg ai/seed)	6.9 b	30.0
NemaStrike™ ST (0.25 mg ai/seed)	6.7 b	32.4
Cultivar x Nematicide		
AG 46X6, non-treated control	4.4	26.4
AG 46X6, Avicta®	2.4	32.0
AG 46X6, ILEVO®	5.2	30.1
AG 46X6, Poncho®/Votivo®	7.1	26.5
AG 46X6, NemaStrike™ ST	6.1	29.3
AG 52X9, non-treated control	3.8	30.1
AG 52X9, Avicta®	7.0	33.4
AG 52X9, ILEVO®	4.1	35.7
AG 52X9, Poncho®/Votivo®	6.7	33.5
AG 52X9, NemaStrike™ ST	9.2	35.5
Statistics: *P* > F		
Cultivar	0.17	0.02
Nematicide	0.03	0.80
Cultivar x Nematicide	0.09	0.88

† Percent of root system galled by root-knot nematode 60 days after planting.
‡ Adjusted to 13% moisture.
§ Numbers within the same column followed by the same letter are not significantly different (P = 0.05) according to Tukey's honestly significant difference test.

Field Performance of Fifty-Six Maturity Group 4 and 5 Soybean Cultivars in a Root-Knot Nematode Infested Field, 2019

M. Emerson[1] *and T. R. Faske*[1]

Abstract

The susceptibility of 56 soybean cultivars to the southern root-knot nematode was evaluated in 2019 in five field trials. In all trials, the damage was severe, with an average population density of 1542 second-stage juveniles/100 cm^3 of soil at harvest. Host susceptibility was based on the percent of root system galled at the R4-R5 growth stage. Cultivars were considered highly resistant if the percentage of root system galled was between 0.0–1.0%, resistant 1.1–4.0%, and moderately resistant 4.1–9.0%. In the maturity group (MG) 4 cultivar trials, GT Ireane and Pioneer P43A42X were considered resistant. Delta Grow DG4940 was highly resistant in the Roundup Ready® and Xtend® trial, while Credenz CZ 4222LL, Credenz CZ 4308LL, Pioneer 45A29L, and Terral REV46L99 were the resistant cultivars in the Liberty Link™ trial. In the MG 5 trial, Delta Grow DG5585, Go Soy 50G17, and Progeny P5554RX were resistant. Armor 55D57, Delta Grow DG54X25, Go Soy 5214, Local Seed LSX 55-19X, Pioneer P55A49X, Terral REV52A98, Terral REV5299XS, and Terral REV5659X were highly resistant in the Roundup Ready and Xtend trial. In the Liberty Link trial, Pioneer P52A43L and Terral REV54L18 were resistant, and Progeny P5414LLS was moderately resistant. These cultivars would be an excellent choice in fields infested with the southern root-knot nematode compared to those that are susceptible.

Introduction

The southern root-knot nematode (RKN), *Meloidogyne incognita*, is one of the most important nematodes of soybean in Arkansas (Kirkpatrick et al., 2014). In a recent survey, more than 28% of the samples collected in soybean fields in the state were infested with RKN (Kirkpatrick, 2017). During the 2015 cropping season, yield losses by RKN in Arkansas were estimated at 6.49 million bushels (Allen et al., 2016).

Management strategies for root-knot nematodes include an integrated approach that utilizes resistant cultivars, crop rotation, and nematicides. Over the past 15 years, the use of seed-applied nematicides has increased; however, they do not provide season-long control. The use of resistant soybean cultivars is the most economical and effective strategy to manage RKN (Kirkpatrick et al., 2014). Since 2017, the Arkansas Soybean Promotion Board has supported the screening and yield potential of soybean cultivars with potential for use in a root-knot nematode field. The objective of this study was to evaluate a few soybean cultivars that are marketed for use in an RKN infested field.

Procedures

Fifty-six soybean cultivars were evaluated in a field with sandy loam soil (48% sand, 48% silt, and 4% clay) that was naturally infested with Meloidogyne incognita near Kerr, Ark. The selected cultivars were among the most common maturity group (MG) 4 and 5 available in the state (Table 1-5). Experiments were divided between MG and herbicide technology. Fertility, irrigation, and weed management followed recommendations by the University of Arkansas System Division of Agriculture's Cooperative Extension Service. Plots were 4 rows wide, 30-ft long, with 30-in. row spacing, and were separated by a 5-ft fallow alley. Seeds were planted using a Kincaid Precision Voltra Vacuum plot planter (Kincaid Equipment Manufacturing, Haven, Kan.) on 28 May 2018 at a seeding rate of 150,000 seeds/ac. The experimental design was a randomized complete block with four replications per cultivar. The population density of RKN at planting averaged 258 second-stage juveniles/100 cm^3 of soil with a final population density at harvest of 1,542 J2/100 cm^3 of soil. The nematode infection rate was based on root galling using a 0–100 percent scale (0–1.0 = highly resistant;

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1.1–4.0 = resistant; 4.1–9.0 = moderately resistant; 9.1–20.0 = moderately susceptible; 20.1–40.0 = susceptible; 40.1–100.0 = highly susceptible) from 8 arbitrarily sampled roots/plot at R4-R5 growth stage. The two center rows of each plot were harvested on 8 Nov. 2019 using a K Gleaner equipped with a Harvest Master weigh system (Harvest Master, Logan, Utah).

Data were subject to analysis of variance using ARM 9 (Gylling Data Management, Inc., Brookings, S.D.). When appropriate, mean separations were performed using Tukey's honestly significant difference (HSD) test at $P = 0.05$.

Results and Discussion

Of the tested MG 4 Roundup Ready/Xtend® cultivars, there was a wide range in susceptibility with 0.9–71.8 % of the root system galled. Overall, galling was lower in this study than in 2018, where >90% galling was observed on the susceptible control cultivar (Emerson et al., 2018). Variation in galling does occur between fields and seasons due to soil type and environmental conditions. Thus, percent galling may be different on individual cultivars than what was observed in this study. It is recommended that cultivar selection be based on two years of data, as several of the cultivars in this study were screened for the first time in 2019. In this test, three cultivars were highly resistant or resistant to the southern root-knot nematode. Delta Grow DG4940 was highly resistant, while GT Ireane and Pioneer P43A42X were resistant, and all had a lower gall rating than Delta Grow DG4880, the susceptible control cultivar (Table 1 and 2). These resistant cultivars had an average grain yield of 72 bu./ac, which was 25 bu./ac greater than the average yield (47 bu./ac) of the susceptible cultivars. In both trials, there was a negative correlation ($r = -0.55$ and $r =-0.74$, respectively; $P \leq 0.001$) between root system galled and yield.

Of the maturity group 4 Liberty™ cultivars, susceptibility ranged 1.5–31.0% of the root system galled. Credenz CZ 4222LL, Credenz CZ 4308LL, Pioneer P45A29, and Terral REV46L99 were rated as resistant and had a lower gall rating than Credenz CZ 4539GTLL the susceptible control cultivar (Table 4). The resistant cultivar grain yield average was 61 bu./ac, which was 1 bu./ac greater than the average yield (60 bu./ac) of the susceptible cultivars. There was no significant correlation ($r = -0.11$, $P = 0.62$) between galling and yield.

Of the maturity group 5 Roundup Ready/Xtend® cultivars, nine were resistant. Susceptibility ranged from 0.2–37.2% of the root system galled. Armor 55D57, Delta Grow DG5585, Go Soy 50G17, Go Soy 5214, Local Seed LSX 55-19X, Pioneer P55A49X, Progeny P5554RX, Terral REV52A98, Terral REV5299XS, and Terral REV5659X were highly resistant to resistant, and all had a lower gall rating than Delta Grow DG5170, the susceptible control cultivar (Table 3). These resistant cultivars grain yield average was 73 bu./ac, which was 21 bu./ac greater than the average yield (52 bu./ac) of the susceptible cultivars. There was a significant negative correlation ($r = -0.55$, $P = 0.0001$) between galling and yield.

In the maturity group 5 Liberty Link cultivars, two of the cultivars were resistant to root-knot nematode, and susceptibility ranged from 1.3–16.4% root system galled. Pioneer P5-2A43L and Terral REV54L18 were resistant and had a lower gall rating than Credenz CZ 5147LL, the susceptible control cultivar (Table 5). The resistant cultivar grain yield average was 73 bu./ac, which was 13 bu./ac greater than the average yield (60 bu./ac) of the susceptible cultivars. There was no significant correlation ($r = -0.38$, $P = 0.16$) between galling and yield.

Practical Applications

Root-knot nematode is an important yield-limiting pathogen that affects soybean production in Arkansas. These data provide information on cultivars susceptibility to the southern root-knot nematode and its impact on susceptible soybean cultivars. Cultivar selection should be based on at least two years of screening as there is variation in galling and yield between seasons.

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Table 1. Root gall ratings and yield from 14 Roundup Ready® and Xtend® maturity group 4 soybean cultivars grown in a root-knot nematode infested field.

Cultivar	Root system galled†	Susceptibility‡	Yield§
	%		bu./ac
GT Ireane	1.9 d¶	R	79.9 a
Pioneer P43A42X	4.0 cd	R	70.7 ab
Dyna Gro S49XT39	34.3 a-d	S	62.6 abc
Delta Grow 48E28	39.0 a-d	S	62.1 abc
Credenz CZ 4979X	22.3 a-d	S	61.2 abc
Armor X48-D88	41.8 a-d	VS	59.3 abc
Local Seed LSX 46-19X	43.1 a-d	VS	55.3 a-d
Credenz CZ 4570X	35.8 a-d	S	55.2 a-d
Progeny P4891E3	39.4 a-d	S	54.5 a-d
Credenz CZ 4869X	59.1 ab	VS	54.2 bcd
Credenz CZ 4770X	17.3 bcd	MS	53.4 bcd
Delta Grow DG4616	29.9 a-d	S	53.1 bcd
Delta Grow DG48X45	60.2 ab	VS	42.7 cd
Local Seed LSX 49-19X	28.0 a-d	S	42.2 cd
Delta Grow DG4880	61.7 ab	VS	39.0 cd
USG 7496XTS	71.8 a	VS	37.2 cd
Asgrow AG 46X6	55.3 abc	VS	32.1 d

† Root gall rating severity was based on a percent scale where 0 = no galling and 100 = 100% of root system galled.
‡ Susceptibility based on percent of root system galled where 0–1.0 = highly resistant; 1.1–4.0 = resistant; 4.1–9.0 = moderately resistant; 9.1–20.0 = moderately susceptible; 20.1–40.0 = susceptible; 40.1–100.0 = highly susceptible.
§ Adjusted to 13% moisture.
¶ Numbers within the same column followed by the same letter are not significantly different (P = 0.05) according to Tukey's honestly significant difference test.

Table 2. Root gall ratings and yield from 14 Roundup Ready® and Xtend® maturity group 4 soybean cultivars grown in a root-knot nematode infested field.

Cultivar	Root system galled†	Susceptibility‡	Yield§
	%		bu./ac
Go Soy 49G16	4.4 bc¶	MR	76.3 a
Dyna Gro S48XT40	6.5 abc	MR	65.6 ab
Go Soy 4914	6.1 abc	MR	65.6 ab
Delta Grow DG4940	0.9 c	HR	64.5 abc
Progeny P4444RXS	4.9 bc	MR	64.3 abc
Go Soy 48X19	17.9 abc	MS	62.4 a-d
NK 45-J3X	19.7 abc	MS	53.0 a-d
Delta Grow 45E23	47.0 ab	VS	42.8 bcd
Credenz CZ 4280X	27.3 abc	S	41.7 bcd
Delta Grow DG4880	48.2 ab	VS	38.3 bcd
Progeny P4525E3	20.5 abc	S	34.8 cd
Delta Grow DG46X25	41.1 abc	VS	33.1 d
USG 7489XT	50.3 a	VS	33.0 d
Credenz CZ 4600X	42.8 abc	VS	32.6 d

† Root gall rating severity was based on a percent scale where 0 = no galling and 100 = 100% of root system galled.
‡ Susceptibility based on percent of root system galled where 0–1.0 = highly resistant; 1.1–4.0 = resistant; 4.1–9.0 = moderately resistant; 9.1–20.0 = moderately susceptible; 20.1–40.0 = susceptible; 40.1–100.0 = highly susceptible.
§ Adjusted to 13% moisture.
¶ Numbers within the same column followed by the same letter are not significantly different (P = 0.05) according to Tukey's honestly significant difference test.

Table 3. Root gall ratings and yield from 18 Roundup Ready® and Xtend® maturity group 5 soybean cultivars grown in a root-knot nematode infested field.

Cultivar	Root system galled †	Susceptibility‡	Yield§
	%		bu./ac
Pioneer P55A49X	0.8 cd¶	HR	86.7 a
Armor 55D57	0.7 cd	HR	80.4 ab
Terral REV5659X	0.9 cd	HR	77.3 ab
Terral REV52A98	0.3 d	HR	72.6 abc
Local Seed LSX 55-19X	0.3 d	HR	72.3 abc
Go Soy 50G17	1.4 cd	R	71.4 abc
Progeny P5554RX	1.1 cd	R	71.1 abc
Delta Drow DG5585	2.7 cd	R	69.7 abc
Terral REV5299XS	0.2 d	HR	67.9 bcd
Go Soy 5214	0.4 d	HR	63.1 b-e
Delta Grow DG54X25	9.0 bc	MR	63.1 b-e
Progeny P5226	23.0 ab	S	58.5 cde
Delta Grow DG5170	37.2 a	S	51.1 de
Progeny P5252RX	15.9 ab	MS	50.7 de
Credenz CZ 5249X	15.3 ab	MS	49.2 e

† Root gall rating severity was based on a percent scale where 0 = no galling and 100 =100% of root system galled.
‡ Susceptibility based on percent of root system galled where 0–1.0 = highly resistant; 1.1–4.0 = resistant; 4.1–9.0 = moderately resistant; 9.1–20.0 = moderately susceptible; 20.1–40.0 = susceptible; 40.1–100.0 = highly susceptible.
§ Adjusted to 13% moisture.
¶ Numbers within the same column followed by the same letter are not significantly different (*P* = 0.05) according to Tukey's honestly significant difference test.

Table 4. Root gall ratings and yield from eight maturity group 4 soybean cultivars grown in a root-knot nematode infested field.

Cultivar	Root system galled†	Susceptibility‡	Yield§
	%		bu./ac
Terral REV46L99	1.5 c¶	R	66.2 a
Pioneer P45A29L	1.8 bc	R	64.1 a
Credenz CZ 4540LL	13.5 a	MS	62.5 a
Credenz CZ4539GTLL	31.0 a	S	60.8 a
Credenz CZ 4222LL	2.6 bc	R	57.5 a
Credenz CZ 4308LL	2.4 c	R	57.3 a

† Root gall rating severity was based on a percent scale where 0 = no galling and 100 = 100% of root system galled.
‡ Susceptibility based on percent of root system galled where 0–1.0 = highly resistant; 1.1–4.0 = resistant; 4.1–9.0 = moderately resistant; 9.1–20.0 = moderately susceptible; 20.1–40.0 = susceptible; 40.1–100.0 = highly susceptible.
§ Adjusted to 13% moisture.
¶ Numbers within the same column followed by the same letter are not significantly different (*P* = 0.05) according to Tukey's honestly significant difference test.

Table 5. Root gall ratings and yield from four maturity group 5 soybean cultivars grown in a root-knot nematode infested field.

Cultivar	Root system galled†	Susceptibility‡	Yield§
	%		bu./ac
Terral REV54L18	1.7 ab¶	R	75.4 a
Pioneer P52A43L	1.3 b	R	71.2 a
Credenz CZ 5147LL	16.4 a	MS	60.4 b
Progeny P5414LLS	6.3 ab	MR	59.2 b

† Root gall rating severity was based on a percent scale where 0 = no galling and 100 = 100% of root system galled.
‡ Susceptibility based on percent of root system galled where 0–1.0 = highly resistant; 1.1–4.0 = resistant; 4.1–9.0 = moderately resistant; 9.1–20.0 = moderately susceptible; 20.1–40.0 = susceptible; 40.1–100.0 = highly susceptible.
§ Adjusted to 13% moisture.
¶ Numbers within the same column followed by the same letter are not significantly different (*P* = 0.05) according to Tukey's honestly significant difference test.

Assessment of Target Spot, Frogeye Leaf Spot, and Cercospora Leaf Blight on Soybean in Arkansas, 2019

A.C. Tolbert,[1] T.N. Spurlock,[1] T. R. Faske,[2] R. Hoyle,[1] and M. Emerson[2]

Abstract

Target spot (caused by *Corynespora cassiicola*), frogeye leaf spot (caused by *Cercospora sojina*), and Cercospora leaf blight (caused by *Cercospora spp*.) are foliar fungal diseases that can cause yield losses on susceptible soybean varieties. Because the preferred means of disease management is genetic resistance, trials to determine the susceptibility of commercially available varieties were completed in 2019 at the University of Arkansas System Division of Agriculture's Rohwer Research Station near Rohwer, Ark, and the University of Arkansas System Division of Agriculture's Newport Extension Center, Newport, Ark. Soybean varieties included in the trials ranged from maturity groups 3.8–5.6 and consisted of conventional soybeans and glyphosate, glufosinate, dicamba, and acetolactate synthase inhibitor resistant/tolerant varieties. The trials were rated for incidence and severity of target spot in addition to Cercospora leaf blight and frogeye leaf spot. Differences in disease incidence and severity of target spot and frogeye leaf spot and disease severity of Cercospora leaf blight were observed at the Rohwer trial. Overall, disease incidence and severity at Newport were too low to be reported.

Introduction

Target spot (TS) is caused by the fungal pathogen *Corynespora cassiicola.* Target spot can be found on nearly all plant parts but is most commonly found on leaves in the lower canopy. Symptoms consist of reddish-brown lesions with a yellow halo, and mature lesions often have concentric rings that lend to the disease's name (Mueller et al., 2016). Infected areas on stems and petioles are dark brown and range from specks to elongated lesions. Initial infections require high humidity (>80%) or free moisture. Drier weather conditions will suppress disease development. Typically, this disease is managed by using high-yielding soybean cultivars, managing surface crop residue, and avoiding soybean monoculture (Faske and Kirkpatrick, 2012). Since the same fungus causes target spot in cotton, a rotation of soybean and cotton can also increase inoculum in soil and on residue from the previous crop. Fungicide efficacy against target spot has been inconsistent as the disease develops in the lower canopy, and it is difficult to get adequate fungicide coverage in the lower canopy.

Frogeye leaf spot (FLS), caused by the fungus *Cercospora sojina* is most often seen during the reproductive growth stages of the plant on newly developed leaves. The disease presents as small irregular to circular shaped lesions with purple borders and light grey to brown centers. In severe cases, lesions will coalesce, forming larger lesions and can cause defoliation. (Mueller et al., 2016)

Cercospora leaf blight (CLB) is caused by multiple species of *Cercospora*. The disease infests the plant in the early vegetative stages, but symptomology does not appear until the reproductive stages. The disease presents as a purpling of the upper leaves progressing to a leathery appearance and appearing bronze in color. (Mueller et al., 2016). Fungicides are not effective when disease symptoms are present. Therefore, the disease must be managed with applications made prior to disease development or by CLB tolerant varieties.

All three of the diseases described require free moisture (dew, rain, high humidity) for an extended period (several hours) in order to develop. Similar weather patterns encourage pathogen spread through sporulation and dissemination of spores to neighboring plants and fields. In addition, all these pathogens overwinter on crop debris. Therefore, the best management practices for all diseases include resistant varieties (known resistances exist for FLS and CLB), crop rotation to a non-host, tillage, and fungicide applications prior to significant disease development. Additionally, fungal populations resistant to strobilurin chemistries exist for FLS, CLB, and TS, requiring the application of fungicides with more than one mode of action (or simply tank-mixing multiple modes of action).

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Procedures

A trial was established at the University of Arkansas System Division of Agriculture's Rohwer Research Station near Rohwer, Ark. in a Herbert silt-loam soil on 28 May on 38-in. row-spacings with plots 2-rows wide and 10-ft long. Seeding rate was 100 seed/plot. A trial was established at the University of Arkansas System Division of Agriculture's Newport Extension Center near Newport, Ark. in a Foley-Calhoun silt loam soil on 1 July on 30 in. row-spacings with plots 1-row wide and 11-ft long. The seeding rate was 115 seed/plot. Soybean varieties (185 total) included in the trials ranged from maturity groups 3.8–5.6 and consisted of conventional soybeans and glyphosate, glufosinate, dicamba, and acetolactate synthase inhibitor resistant/tolerant varieties. For the Rohwer site, disease incidence assessments were taken based on the percentage of plants per plot affected. Disease severity assessments were taken 12 Sept. using a percentage scale where 0 = no disease and 100 = dead plants. The trial was harvested 9 Oct. with a plot combine. Yield data were adjusted to 13% moisture content for comparison. Because there was no measurable foliar disease at the Newport site, no disease data are reported. Data were subjected to analysis of variance followed by means separation of fixed effects using Tukey's honestly significant difference (HSD) at $P = 0.10$ across maturity groups.

Results and Discussion

At the Rohwer location, soybean varieties differed in response to the incidence and severity of TS and FLS, but only to the severity of CLB (Table 1-5). Target spot incidence ranged from 0.0–86.7%, with an average of 25.8%. Target spot severity ranged from 0.0–10.0%, with an average of 1.1%. Average CLB incidence was 48.4% ranging from 0.0–90.0%. Average CLB severity was 3.5% ranging from 0.0–36.7%. Frogeye leaf spot incidence ranged from 0.0–66.7%, with an average of 21.9% FLS severity ranged from 0.0–5.7%, with an average of 0.7%. Yield ranged from 24.8–118.8 bu./ac, with an average of 75.8 bu./ac. Data are arranged in 5 tables by maturity group. Table 1 contains 3.8–4.5 maturity group (MG), Table 2 contains 4.6–4.7 MGs, Table 3 contains 4.8 MG, Table 4 contains 4.9–5.1 MGs, and Table 5 contains 5.2–5.6 MG data. Overall, disease severity of these foliar diseases was lower than that observed in 2018 at Rohwer (Tolbert et al., 2019). Because there was no foliar disease development at the Newport location, no data are reported.

Practical Applications

The potential for foliar disease development in soybean can be severe in Arkansas when disease occurs on a susceptible variety, and conditions favor disease development. Soybean breeders are constantly developing new varieties with resistance genes and greater yield potential. It is important that farmers be informed on varietal susceptibility to foliar disease prior to planting so sound management decisions can be made during the season. The information reported in this study can aid in disease management decisions and potentially save input expenses, particularly in fields with a history of foliar diseases. These results are a valuable tool to help minimize yield loss from TS, CLB, and FLS.

Acknowledgments

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Table 1. Soybean maturity groups 3.8-4.5 percent incidence and severity of target spot, Cercospora leaf blight, and frogeye leaf spot at the University of Arkansas System Division of Agriculture's Rohwer Research Station, 2019.

Variety	MG	Tech	TS† I‡	TS S‡	CLB† I	CLB S	FLS† I	FLS S	Yield
			----------------	----------------	--------	%	--------	----------------	bu./ac
Credenz CZ3841LL	3.8	LL	0.0 d§	0.0 e	0.0	0.0 c	0.0	0.0 d	35.0 hi
Credenz CZ3929GTLL	3.9	GT/LL	73.3 a-d	1.0 de	73.3	7.3 bc	10.0	0.7 cd	84.5 a-h
Local LS3976X	3.9	Xtend	0.0 d	0.0 e	56.7	-	60.0	1.0 bcd	73.5 a-i
NK S39-G2X	3.9	Xtend	0.0 d	0.0 e	60.0	-	46.7	1.0 bcd	62.2 b-i
Dyna-Gro S41XS98	4.1	Xtend /STS	0.0 d	0.0 e	43.3	0.0 c	40.0	0.7 cd	60.8 b-i
S13-2743C	4.1	Conv.	0.0 d	0.0 e	45.0	5.0 bc	0.0	0.0 d	n/a
Armor 42-D27	4.2	Xtend	0.0 d	0.0 e	16.7	0.3 c	23.3	0.3 d	80.7 a-h
Asgrow AG42X9	4.2	Xtend	0.0 d	0.0 e	46.7	3.7 bc	30.0	0.7 cd	67.6 a-i
Credenz CZ4222LL	4.2	LL	0.0 d	0.0 e	0.0	0.0 c	0.0	0.0 d	68.9 a-i
Credenz CZ4280X	4.2	Xtend	0.0 d	0.0 e	50.0	3.7 bc	30.0	0.7 cd	88.8 a-h
Dyna-Gro S42EN89	4.2	Enlist	46.7 a-d	2.3 cde	53.3	8.3 bc	0.0	0.0 d	81.4 a-h
Local LSX4301XS	4.2	Xtend	0.0 d	0.0 e	26.7	6.7 bc	23.3	0.3 d	80.0 a-i
Pioneer P42A96X	4.2	Xtend	0.0 d	0.0 e	56.7	10.3 bc	40.0	0.7 cd	84.4 a-h
Progeny P4241 E3	4.2	E3	0.0 d	0.0 e	0.0	0.0 c	0.0	0.0 d	56.4 b-i
Progeny P4255RX	4.2	Xtend	0.0 d	0.0 e	26.7	3.3 bc	13.3	0.3 d	91.0 a-g
Progeny P4265RXS	4.2	Xtend /STS	0.0 d	0.0 e	60.0	10.0 bc	43.3	0.7 cd	76.7 a-i
Progeny P4291LR	4.2	LL /GT27	83.3 ab	2.0 cde	70.0	1.3 bc	36.7	1.0 bcd	86.3 a-h
Asgrow AG43X0	4.3	Xtend	13.3 a-d	0.3 de	23.3	0.3 c	16.7	0.3 d	74.9 a-i
REV4310X	4.3	Xtend	0.0 d	0.0 e	66.7	1.0 bc	63.3	1.0 bcd	85.5 a-h
AgriGold G4440RX	4.4	Xtend	0.0 d	0.0 e	50.0	3.7 bc	36.7	0.7 cd	91.9 a-g
Armor 44-D92	4.4	Xtend	20.0 a-d	0.3 de	50.0	1.3 bc	36.7	0.7 cd	79.0 a-i
Delta Grow 45E23	4.4	E3	0.0 d	0.0 e	0.0	0.0 c	3.3	0.3 d	57.9 b-i
Eagle Seed ES4460RYX	4.4	Xtend	0.0 d	0.0 e	56.7	14.0 bc	40.0	0.7 cd	80.4 a-i
Local LS4487XS	4.4	Xtend	23.3 a-d	0.7 de	56.7	7.0 bc	30.0	0.7 cd	79.2 a-i
Mission A4448X	4.4	Xtend	16.7 a-d	0.3 de	53.3	1.0 bc	43.3	0.7 cd	91.8 a-g
MorSoy 4447 RXT	4.4	Xtend	16.7 a-d	0.7 de	56.7	5.7 bc	30.0	0.7 cd	96.1 a-g
NK S44-C7X	4.4	Xtend	10.0 a-d	0.3 de	50.0	10.3 bc	40.0	0.7 cd	90.5 a-h
Progeny P4444RXS	4.4	Xtend /STS	0.0 d	0.0 e	53.3	0.7 bc	40.0	0.7 cd	85.9 a-h
S13-3851C	4.4	Conv.	0.0 d	0.0 e	9.0	1.0 bc	22.0	2.3 bcd	49.9 c-i
AgriGold G4579RX	4.5	Xtend	0.0 d	0.3 de	60.0	7.3 bc	30.0	1.0 bcd	97.4 a-g
Armor X45D51	4.5	Xtend	0.0 d	0.0 e	50.0	1.3 bcd	43.3	7.0 bc	96.5 a-f
Credenz CZ4539GTLL	4.5	GT/LL	76.7 a-d	2.3 cde	26.7	0.7 cd	66.7	3.7 bc	97.4 a-g
Credenz CZ4540LL	4.5	LL	0.0 d	0.0 e	20.0	1.0 bc	0.0	0.0 d	82.8 a-h
Credenz CZ4570X	4.5	Xtend	0.0 d	0.0 e	76.7	2.7 bc	53.3	1.0 bcd	88.4 a-h
Dyna-Gro S45XS37	4.5	Xtend /STS	0.0 d	0.0 e	30.0	6.7 bc	26.7	0.7 cd	91.4 a-g
Dyna-Gro S45XS66	4.5	Xtend /STS	0.0 d	0.3 de	53.3	10.0 bc	40.0	0.7 cd	97.1 a-f
Local LS4565XS	4.5	Xtend	0.0 d	0.0 e	26.7	1.3 bc	10.0	0.3 d	83.8 a-h
Local LS4583X	4.5	Xtend	0.0 d	0.0 e	26.7	0.3 c	10.0	0.3 d	74.6 a-i
Local LSX4501X	4.5	Xtend	0.0 d	0.0 e	20.0	0.3 c	10.0	0.3 d	85.0 a-h
Local LSX4503GTLL	4.5	GT/LL	70.0 a-d	1.0 de	66.7	3.7 bc	40.0	1.0 bcd	85.0 a-h
Progeny P4525 E3	4.5	E3	36.7 a-d	2.0 cde	6.7	1.5 bc	0.0	0.0 dc	41.6 f-i
Progeny P4565LR	4.5	LL /GT27	40.0 a-d	1.0 de	50.0	2.3 bc	3.3	0.3 d	100.1 a-e

† Target spot (TS), Cercospora leaf blight (CLB), and frogeye leaf spot (FLS).

‡ Incidence (I) 0 = no disease, and 100 = all plants with symptoms and severity (S) where 0 = no disease, and 100 = all plants dead.

§ Columns followed by the same letter are not statistically significant at $P = 0.10$ as determined by Tukey's honestly significant difference test.

Table 2. **Soybean maturity groups 4.6-4.7 percent incidence and severity of target spot, Cercospora leaf blight, and frogeye leaf spot at the University of Arkansas System Division of Agriculture's Rohwer Research Station, 2019.**

Variety	MG	Tech	TS† I‡	TS S‡	CLB† I	CLB S	FLS† I	FLS S	Yield
			--------------------------------	-------	----	---%---	----	-------	bu./ac
AgriGold G4605RX	4.6	Xtend	13.3a-d†	0.0 e	30.0	6.7 bc	6.7	0.3 d	74.6 a-i
Armor X46D09	4.6	Xtend	0.0 d	0.0 e	73.3	7.3 bc	40.0	1.0 bcd	98.2 a-e
Armor X46D30	4.6	Xtend	20.0 a-d	0.3 de	90.0	21.7 ab	16.7	1.0 bcd	98.2 a-e
Asgrow AG46X0	4.6	Xtend	0.0 d	0.0 e	46.7	7.0 bc	26.7	1.0 bcd	69.1 a-i
Asgrow AG46X6	4.6	Xtend	0.0 d	0.0 e	26.7	3.3 bc	26.7	0.7 cd	90.0 a-h
Credenz CZ4600X	4.6	Xtend	30.0 a-d	0.7 de	46.7	1.0 bc	43.3	1.0 bcd	63.0 b-i
Credenz CZ4649LL	4.6	LL	0.0 d	0.0 e	56.7	5.0 bc	0.0	0.0 d	88.0 a-h
Delta Grow 46E29	4.6	E3/STS	26.7 a-d	0.7 de	3.3	0.3 c	3.3	0.3 d	50.5 c-i
Delta Grow 46X25	4.6	Xtend	0.0 d	0.0 e	80.0	1.0 bc	46.7	1.0 bcd	99.3 a-e
Delta Grow 46X65	4.6	Xtend/STS	0.0 d	0.0 e	66.7	1.0 bc	46.7	1.0 bcd	74.1 a-i
Dyna-Gro S46EN29	4.6	Enlist	66.7 a-d	2.3 cde	50.0	1.0 bc	10.0	0.3 d	87.3 a-h
Dyna-Gro S46XS60	4.6	Xtend/STS	6.7 bcd	0.3 de	66.7	2.3 bc	66.7	1.3 bcd	69.0 a-i
Eagle Seed ES4680RYX	4.6	Xtend	0.0 d	0.0 e	0.0	0.0 c	0.0	0.0 d	77.4 a-i
Go Soy 46GL18	4.6	LL/GT27	36.7 a-d	1.0 de	56.7	1.0 bc	0.0	0.0 d	63.9 a-i
Hefty H46X0S	4.6	Xtend	16.7 a-d	0.3 de	60.0	1.0 bc	46.7	1.0 bcd	90.2 a-h
LGS4420RX	4.6	Xtend	16.7 a-d	0.7 de	16.7	0.3 c	10.0	0.3 d	73.0 a-i
Local LS4677X	4.6	Xtend	16.7 a-d	0.0 e	73.3	17.0 a-c	26.7	1.0 bcd	71.0 a-i
Local LSX4601XS	4.6	Xtend	0.0 d	0.3 de	13.3	0.3 c	10.0	0.3 d	88.8 a-h
Local LSX4602ES	4.6	Xtend	53.3 a-d	1.0 de	60.0	2.3 bc	13.3	0.7 cd	104.5 a-c
Mission A4618X	4.6	Xtend	16.7 a-d	0.7 de	36.7	2.0 bc	10.0	0.3 d	60.7 b-i
Pioneer P46A57BX	4.6	Xtend	13.3 a-d	1.7 de	56.7	10.3 bc	20.0	0.7cd	83.9 a-h
Progeny P4620RXS	4.6	Xtend/STS	43.3 a-d	1.0 de	90.0	36.7 a	53.3	3.7 abc	62.0 b-i
Progeny P4670RX	4.6	Xtend	0.0 d	0.0 e	60.0	1.0 bc	20.0	1.3 bcd	89.2 a-h
Progeny P4682 E3	4.6	E3	13.3 a-d	1.7 de	10.0	0.3 c	10.0	0.7 cd	44.9 e-i
R16-253	4.6	Conv.	0.0 d	0.0 e	20.0	2.7 bc	2.7	1.0 bcd	118.8 a
R16-259	4.6	Conv.	0.0 d	0.0 e	19.0	4.0 bc	4.3	1.0 bcd	59.4 b-i
REV 4679X	4.6	Xtend	23.3 a-d	0.0 e	80.0	20.3 a-c	30.0	0.7 cd	103.3 a-d
USG 7460ET	4.6	Enlist	63.3 a-d	2.3 cde	66.7	1.0 bc	0.0	0.0 d	82.0 a-h
Armor X47D18	4.7	Xtend	0.0 d	0.0 e	66.7	1.3 bc	56.7	1.3 bcd	93.7 a-g
Armor X47D85	4.7	Xtend	13.3 a-d	0.3 de	63.3	2.3 bc	40.0	1.3 bcd	74.8 a-i
Armor X47D86	4.7	Xtend	13.3 a-d	0.3 de	73.3	1.7 bc	50.0	1.0 bcd	92.0 a-g
Asgrow AG47X0	4.7	Xtend	0.0 d	0.0 e	73.3	1.0 bc	50.0	1.3 bcd	84.6 a-h
Asgrow AG47X9	4.7	Xtend	30.0 a-d	0.7 de	73.3	2.3 bc	33.3	1.0 bcd	72.5 a-i
Credenz CZ4770X	4.7	Xtend	10.0 a-d	2.0 cde	60.0	4.0 bc	43.3	2.3 bcd	99.6 a-e
Delta Grow 47E19	4.7	E3	0.0 d	0.0 e	15.0	1.5 bc	0.0	0.0 d	79.5 a-i
Delta Grow 47E25	4.7	E3	0.3 d	0.0 e	13.3	1.0 bc	0.0	0.0 d	74.3 a-i
DM 47X01	4.7	Xtend	40.0 a-d	1.0 de	70.0	4.3 bc	30.0	0.7 de	84.9 a-h
Dyna-Gro S47XT20	4.7	Xtend	3.3 cd	0.3 de	73.3	2.3 bc	43.3	1.0 bcd	92.9 a-g
Local LS4798X	4.7	Xtend	20.0 a-d	1.7 de	63.3	14.0 bc	53.3	1.0 bcd	86.1 a-h
Local LSX4701E	4.7	Enlist	86.7 a	5.0 bcd	70.0	7.0 bc	23.3	0.7 cd	90.7 a-h
MorSoy 4706 RXT	4.7	Xtend	20.0 a-d	0.7 de	76.7	1.3 bc	43.3	1.0 bcd	95.5 a-g
Progeny P4710 E3	4.7	E3	10.0 a-d	0.3 de	11.7	1.0 bc	6.7	0.7 cd	68.1 a-i
Progeny P4775 E3S	4.7	E3/STS	26.7 a-d	3.7 b-e	13.3	1.3 bc	23.3	2.0 bcd	55.1 b-i
Progeny P4799RXS	4.7	Xtend/STS	10.0 a-d	0.3 de	53.3	0.7 bc	26.7	0.7 cd	73.3 a-i
R15-2422	4.7	Conv.	0.0 d	0.0 e	51.3	1.7 bc	63.3	5.7 a	62.5 b-i
USG 7470XT	4.7	Xtend	3.3 cd	0.3 de	76.7	1.0 bc	43.3	1.3 bcd	88.3 a-h
USG 7478XTS	4.7	Xtend/STS	0.0 d	0.0 e	66.7	4.0 bc	30.0	0.7 cd	76.6 a-i

† Target spot (TS), Cercospora leaf blight (CLB), and frogeye leaf spot (FLS).

‡ Incidence (I) 0 = no disease, and 100 = all plants with symptoms and severity (S) where 0 = no disease, and 100 = all plants dead.

§Columns followed by the same letter are not statistically significant at $P = 0.10$ as determined by Tukey's honestly significant difference test.

Table 3. Soybean maturity group 4.8 percent incidence and severity of target spot, Cercospora leaf blight, and frogeye leaf spot at the University of Arkansas System Division of Agriculture's Rohwer Research Station, 2019.

Variety	MG	Tech	TS† I‡	TS S‡	CLB† I	CLB S	FLS† I	FLS S	Yield
			------------------------------%-----------------------------------						bu./ac
AgriGold G4815RX	4.8	Xtend	30.0 a-d§	2.0 cde	36.7	1.0 bc	23.3	0.7 cd	47.7 d-i
AGS GS48X19	4.8	Xtend	26.7 a-d	0.7 de	53.3	0.7 bc	23.3	0.7 cd	81.9 a-h
Armor X48D25	4.8	Xtend	63.3 a-d	1.3 de	26.7	0.7 bc	40.0	0.7 cd	69.2 a-i
Armor X48D88	4.8	Xtend	63.3 a-d	2.7 cde	63.3	7.0 bc	6.7	0.3 d	69.6 a-1
Asgrow AG48X9	4.8	Xtend	40.0 a-d	1.3 de	63.3	1.0 bc	30.0	2.3 bcd	61.1 b-i
Credenz CZ4820LL	4.8	LL	50.0 a-d	8.3 ab	36.7	7.3 bc	0.0	0.0 d	75.2 a-i
Credenz CZ4869X	4.8	Xtend	30.0 a-d	1.0 de	73.3	1.3 bc	30.0	0.7 cd	48.2 d-i
Delta Grow 48E10	4.8	E3	21.7 a-d	2.0 cde	30.0	3.7 bc	0.0	0.0 d	46.4 e-i
Delta Grow 48E39	4.8	E3	20.0 a-d	2.3 cde	10.0	2.3 bc	0.0	0.0 d	56.5 b-i
Delta Grow 48E49	4.8	E3/ STS	43.3 a-d	5.0 bcd	16.7	1.3 bc	3.3	0.3 d	94.0 a-g
Delta Grow 48X45	4.8	Xtend	53.3 a-d	1.0 de	66.7	1.0 bc	30.0	0.7 cd	40.5 ghi
DM 48E01	4.8	Enlist	53.3 a-d	1.0 de	53.3	11.7 bc	0.0	0.0 d	59.8 b-i
Dyna-Gro S48XT56	4.8	Xtend	56.7 a-d	1.3 de	56.7	1.0 bc	46.7	1.0 bcd	67.7 a-i
Eagle Seed ES4840RYX	4.8	Xtend	50.0 a-d	2.3 cde	66.7	4.0 bc	36.7	1.0 bcd	63.1 a-i
Go Soy 481E19	4.8	E3	3.3 cd	0.3 de	15.0	1.7 bc	0.0	0.0 d	54.2 b-i
Go Soy 482E18	4.8	E3	36.7 a-d	4.0 b-e	70.0	15.0 a-c	0.0	0.0 d	75.4 a-i
Go Soy 48C17S	4.8	Conv.	0.0 d	0.0 e	30.0	1.7 bc	0.7	0.7 cd	24.8 i
Hefty H48E0	4.8	E3	23.3 a-d	2.3 cde	18.3	2.3 bc	0.0	0.0 d	107.4 ab
Hefty H48E9	4.8	E3	30.0 a-d	2.3 cde	70.0	15.0 bc	0.0	0.0 d	86.4 a-h
LGC4845RX	4.8	Xtend	50.0 a-d	1.0 de	60.0	2.3 bc	33.3	1.0 bcd	90.2 a-h
LGS4899RX	4.8	Xtend	58.3 a-d	3.3 cde	56.7	1.0 bc	50.0	1.0 bcd	58.3 b-i
Local LS4889XS	4.8	Xtend	46.7 a-d	1.0 de	16.7	0.3 c	10.0	0.3 d	79.2 a-i
Local LSX4801X	4.8	Xtend	40.0 a-d	0.7 de	63.3	1.3 bc	10.0	0.3 d	63.0 b-i
MorSoy 4846 RXT	4.8	Xtend	43.3 a-d	2.3 cde	80.0	2.3 bc	13.3	0.3 d	62.7 b-i
Pioneer P48A60X	4.8	Xtend	46.7 a-d	2.3 cde	13.3	0.3 c	13.3	0.3 d	67.5 a-i
Pioneer P48A99L	4.8	LL	66.7 a-d	10.0 a	33.3	8.7 bc	0.0	0.0 d	71.6 a-i
Progeny P4816RX	4.8	Xtend	43.3 a-d	1.0 de	66.7	1.0 bc	63.3	1.7 bcd	66.8 a-i
Progeny P4821RX	4.8	Xtend	40.0 a-d	2.0 cde	53.3	1.0 bc	40.0	1.0 bcd	61.7 b-i
Progeny P4833 E3	4.8	E3	33.3 a-d	3.7 b-e	31.7	4.0 bc	0.0	0.0 d	86.3 a-h
Progeny P4851RX	4.8	Xtend	56.7 a-d	1.0 de	40.0	0.7 bc	33.3	1.0 bcd	79.6 a-i
Progeny P4891 E3	4.8	E3	16.7 a-d	0.7 de	43.3	4.0 bc	3.3	0.3 d	94.0 a-g
S14-15138R	4.8	RR1/ STS	36.7 a-d	0.7 de	66.7	1.0 bc	13.3	0.3 d	82.0 a-h
USG 7480ET	4.8	Enlist	80.0 a-c	3.7 b-e	50.0	10.3 bc	0.0	0.0 d	70.1 a-i
USG 7480XT	4.8	Xtend	30.0 a-d	1.0 de	76.7	1.0 bc	40.0	1.0 bcd	61.8 b-i
USG 7489XT	4.8	Xtend	40.0 a-d	1.0 de	36.7	0.7 bc	53.3	1.3 bcd	71.2 a-i

† Target spot (TS), Cercospora leaf blight (CLB), and frogeye leaf spot (FLS).

‡ Incidence (I) 0 = no disease, and 100 = all plants with symptoms and severity (S) where 0 = no disease, and 100 = all plants dead.

§ Columns followed by the same letter are not statistically significant at $P = 0.10$ as determined by Tukey's honestly significant difference test.

Table 4. Soybean maturity groups 4.9-5.1 percent incidence and severity of target spot, Cercospora leaf blight, and frogeye leaf spot at the University of Arkansas System Division of Agriculture's Rohwer Research Station, 2019.

Variety	MG	Tech	TS† I‡	TS S‡	CLB† I	CLB S	FLS† I	FLS S	Yield
			---------------	-------	-------	%	-------	---------------	bu./ac
AGS GS49X19	4.9	Xtend	50.0 a-d§	1.0 de	88.3	7.0 bc	30.0	1.0 bcd	74.6 a-i
Armor X49D67	4.9	Xtend	53.3 a-d	1.3 de	70.0	1.3 bc	26.7	1.0 bcd	62.3 b-i
Asgrow AG49X9	4.9	Xtend	70.0 a-d	2.3 cde	73.3	4.0 bc	40.0	1.0 bcd	83.6 a-h
Credenz CZ4918LL	4.9	LL	43.3 a-d	4.0 b-d	26.7	3.7 bc	0.0	0.0 d	66.8 a-i
Credenz CZ4938LL	4.9	LL	3.3 cd	0.3 de	36.7	3.7 bc	0.0	0.0 d	60.3 b-i
Credenz CZ4979X	4.9	Xtend	36.7 a-d	1.3 de	80.0	2.3 bc	0.0	0.0 d	63.6 a-i
Delta Grow 4977LL/STS	4.9	LL/ STS	56.7 a-d	6.7 abc	80.0	8.3 bc	0.0	0.0 d	73.2 a-i
Delta Grow 49E29	4.9	E3	0.0 d	0.0 e	53.3	6.7 bc	0.0	0.0 d	75.9 a-i
Delta Grow 49X15	4.9	Xtend	43.3 a-d	1.0 de	10.0	1.0 bc	3.3	0.3 d	76.8 a-i
Dyna-Gro S49EN79	4.9	Enlist	83.3 ab	3.7 b-e	43.3	4.3 bc	10.0	0.3 d	61.2 b-i
Dyna-Gro S49XT39	4.9	Enlist	50.0 a-d	1.3 de	83.3	4.3 bc	40.0	0.7 cd	82.9 a-h
Dyna-Gro S49XT70	4.9	Xtend	56.7 a-d	1.0 de	57.6	1.0 bc	43.3	1.0 bcd	93.2 a-g
Go Soy 49G16	4.9	RR1	23.3 a-d	0.7 de	80.0	1.7 bc	10.0	0.3 d	91.7 a-g
LGS4931RX	4.9	Xtend	73.3 a-d	2.7 cde	90.0	4.7 bc	66.7	2.0 bcd	84.2 a-h
Local LSX4901X	4.9	Xtend	40.0 a-d	1.0 de	63.3	1.0 bc	26.7	0.7 cd	90.3 a-h
Mission A4950X	4.9	Xtend	40.0 a-d	0.7 de	50.0	2.7 bc	40.0	0.7 cd	87.5 a-h
NK S49-F5X	4.9	Xtend	36.7 a-d	1.0 de	33.3	0.7 bc	30.0	1.0 bcd	80.2 a-i
Petrus Seed 4916GT	4.9	RR1	13.3 a-d	0.3 de	70.0	1.0 bc	26.7	0.7 cd	72.6 a-i
Progeny P4999RX	4.9	Xtend	40.0 a-d	0.7 de	63.3	1.3 bc	13.3	0.3 d	81.7 a-h
REV 4927X	4.9	Xtend	20.0 a-d	0.7 de	36.7	0.7 bc	26.7	0.7 cd	85.5 a-h
REV 4940X	4.9	Xtend	85.0 a	4.7 b-e	80.0	1.3 bc	36.7	1.0 bcd	89.5 a-h
USG 7496XTS	4.9	Xtend/ STS	53.3 a-d	1.3 de	83.3	1.7 bc	50.0	1.3 bcd	88.9 a-h
AgriGold G5000RX	5.0	Xtend	26.7 a-d	0.7 de	70.0	1.3 bc	0.0	0.0 d	62.3 b-i
Go Soy 50G17	5.0	RR1	13.3 a-d	0.3 de	70.0	1.0 bc	53.3	1.3 bcd	69.3 a-i
Local LS5087X	5.0	Xtend	40.0 a-d	0.7 de	76.7	1.0 bc	10.0	0.3 d	69.5 a-i
Progeny P5016RXS	5.0	Xtend/ STS	26.7 a-d	0.7 de	43.3	3.7 bc	0.0	0.0 d	53.4 b-i
Armor 51-D77	5.1	Xtend	26.7 a-d	1.0 de	76.3	1.7 bc	6.7	0.3 d	66.1 a-i
Credenz CZ5150LL	5.1	LL	13.3 a-d	1.0 de	16.7	4.0 bc	0.0	0.0 d	81.2 a-h
Eagle Seed ES5155RYX	5.1	Xtend	56.7 a-d	4.0 b-e	53.3	1.3 bc	46.7	1.3 bcd	73.3 a-i
Go Soy 512E18	5.1	E3	0.0 d	0.0 e	13.3	2.3 bc	13.3	0.7 cd	87.1 a-h
Hefty H51E9	5.1	E3	0.0 d	0.0 e	20.0	2.3 bc	6.7	0.3 d	71.1 a-i
Progeny P5170RX	5.1	Xtend	56.7 a-d	1.3 de	66.7	1.3 bc	50.0	1.3 bcd	73.3 a-i
R15-1587	5.1	Conv.	0.0 d	0.0 e	1.0	1.3 bc	1.0	0.7 cd	56.4 b-i
R16-2546C	5.1	Conv.	0.0 d	0.0 e	0.7	0.7 bc	1.7	1.0 bcd	59.1 b-i
R16-39	5.1	Conv.	0.0 d	0.0 e	2.7	1.0 bc	1.3	1.0 bcd	55.4 b-i

† Target spot (TS), Cercospora leaf blight (CLB), and frogeye leaf spot (FLS).

‡ Incidence (I) 0 = no disease, and 100 = all plants with symptoms and severity (S) where 0 = no disease, and 100 = all plants dead.

§ Columns followed by the same letter are not statistically significant at $P = 0.10$ as determined by Tukey's honestly significant difference test.

Table 5. Soybean maturity groups 5.2-5.6 percent incidence and severity of target spot, Cercospora leaf blight, and frogeye leaf spot at the University of Arkansas System Division of Agriculture's Rohwer Research Station, 2019.

Variety	MG	Tech	TS† I‡	TS S‡	CLB† I	CLB S	FLS† I	FLS S	Yield
			----------------------------------	----------	-----------	--%	------------------	----------------------------------	bu./ac
Armor 52-D71	5.2	Xtend	40.0 a-d§	1.0 de	46.7	1.0 bc	6.7	0.3 d	75.1 a-i
Asgrow AG52X9	5.2	Xtend	46.7 a-d	1.3 de	43.3	1.0 bc	0.0	0.0 d	72.1 a-i
Credenz CZ5299X	5.2	Xtend	30.0 a-d	1.3 de	40.0	1.3 bc	20.0	0.7 cd	78.0 a-i
Delta Grow 52E22	5.2	E3	0.0 d	0.0 e	10.0	1.0 bc	3.3	0.3 d	64.5 a-i
Delta Grow 52X05	5.2	Xtend/ STS	56.7 a-d	1.0 de	44.3	2.3 bc	0.0	0.0 d	77.5 a-i
Dyna-Gro S52XS39	5.2	Xtend/ STS	46.7 a-d	1.3 de	46.7	2.3 bc	3.3	0.3 d	83.9 a-h
Progeny P5211 E3	5.2	E3	0.0 d	0.0 e	26.7	2.3 bc	6.7	0.7 cd	64.4 a-i
Progeny P5252RX	5.2	Xtend	50.0 a-d	4.3 b-e	40.0	1.3 bc	3.3	0.3 d	85.2 a-h
R16-2547	5.2	Conv.	0.0 d	0.0 e	43.3	2.0 bc	1.0	0.7 cd	53.9 b-i
Asgrow AG53X0	5.3	Xtend	50.0 a-d	2.7 cde	63.3	1.3 bc	3.3	0.3 d	62.0 b-i
Local LS5386X	5.3	Xtend	56.7 a-d	1.3 de	60.0	5.7 bc	0.0	0.0 d	83.2 a-h
Progeny P5335RX	5.3	Xtend	46.7 a-d	1.0 de	53.3	1.0 bc	13.3	0.3 d	70.2 a-i
R13-818	5.3	Conv.	0.0 d	0.0 e	28.3	2.0 bc	0.7	0.7 cd	56.7 b-i
Delta Grow 54X25	5.4	Xtend	80.0 abc	2.7 cde	60.0	4.0 bc	0.0	0.0 d	80.4 a-i
R13-13997	5.4	Conv.	0.0 d	0.0 e	3.7	1.3 bc	0.7	0.7 cd	79.0 a-i
R13-14635RR	5.4	RR1	30.0 a-d	0.7 de	86.7	2.7 bc	17.7	1.7 bcd	82.8 a-h
R14-1422	5.4	Conv.	0.0 d	0.0 e	28.3	1.7 bc	1.0	1.0 bcd	74.5 a-i
R16-1445	5.4	Conv	0.0 d	0.0 e	18.7	1.3 bc	0.7	0.7 cd	85.2 a-h
R16-378	5.4	Conv.	0.0 d	0.0 e	20.0	2.0 bc	17.3	1.0 bcd	80.5 a-i
Armor 55-D57	5.5	Xtend	40.0 a-d	1.0 de	56.7	1.3 bc	10.0	0.7 cd	54.1 b-i
Delta Grow 5585RR2	5.5	RR2	13.3 a-d	0.3 de	73.3	1.3 bc	33.3	1.0 bcd	75.7 a-i
Local LS5588X	5.5	Xtend	53.3 a-d	1.0 de	66.7	1.3 bc	13.3	0.7 cd	56.3 b-i
Progeny P5554RX	5.5	Xtend	56.7 a-d	1.3 de	70.0	2.3 bc	20.0	0.7 cd	73.8 a-i
Dyna-Gro S56XT99	5.6	Xtend	26.7 a-d	1.0 de	66.7	12.0 bc	20.0	0.7 cd	61.6 b-i
Progeny P5688RX	5.6	Xtend	60.0 a-d	1.0 de	53.3	2.3 bc	16.7	0.7 cd	84.4 a-h

† Target spot (TS), Cercospora leaf blight (CLB), and frogeye leaf spot (FLS).

‡ Incidence (I) 0 = no disease, and 100 = all plants with symptoms and severity (S) where 0 = no disease, and 100 = all plants dead.

§ Columns followed by the same letter are not statistically significant at $P = 0.10$ as determined by Tukey's honestly significant difference test.

Taproot Decline Trial Summaries 2018–2019

T.N. Spurlock,[1] A.C. Tolbert,[1] and R. Hoyle[1]

Abstract

Taproot decline (TRD) of soybean is an emerging disease with the capability to decrease yield significantly. Over the past two years, distributions of TRD occurrence in the soybean production areas of Arkansas were examined at the field level and within the field. The distribution of TRD has been confirmed in 11 counties of the Arkansas delta region. Field distributions are clustered, which is typical of soil-borne diseases. Seed treatment fungicide efficacy trials indicate thiabendizole and thiophanate-methyl chemistries may have some activity against TRD. However, results with seed treatments have been less consistent than with in-furrow fungicide treatments. Variety trials have also been conducted to identify varietal resistance and/or tolerance, if any exist.

Introduction

A group of scientists from the University of Arkansas System Division of Agriculture, Mississippi State University, and Louisiana State University has characterized a disease of soybean [*Glycine max* (L.) Merr.] prevalent in their respective states and named it taproot decline (TRD) (Allen et al., 2017). It was determined that the disease is caused by an undescribed fungus in the genus *Xylaria*. The disease presents in early vegetative stages as chlorotic or dead plants located in clusters or streaks. Additionally, in areas of symptomatic plants, gaps in plant stands are evident with mummies of dead plants between the chlorotic plants. When dead plants from TRD are extracted from the soil, the taproot will be malformed and black, if present. In the latter reproductive stages (R5+, beginning seed development), the disease has a "leopard spot" or "sanded" appearance. As the disease progresses, above-ground symptoms include stunting and interveinal chlorosis leading to necrosis. When a plant with TRD is pulled from the soil at this growth stage, the taproot will often break off and have a black coating of stroma. Splitting the root or lower stem longitudinally reveals mild vascular staining, and often white mycelia are seen growing up the pith. Fungal fruiting structures referred to as "dead man's fingers" can sometimes be found in the residue from the previous year's crop as well.

The regional distributions and yield loss in Arkansas have been unclear to date. However, it has been found as far north as Craighead County, and reports from some farmers and consultants indicate yield losses as high as 10 bu./ac in fields. Currently, we do not have seed treatment fungicide or varietal recommendations for growers to combat TRD. The objectives of the following studies were to determine the distribution of TRD across the soybean production areas in Arkansas, determine disease severity on commonly planted varieties, determine the efficacy of fungicide seed treatments against TRD, and to determine the field distribution and yield impact. Understanding the regional distribution, commercially available seed treatment efficacy, and varietal susceptibilities are necessary for the successful management of this disease in Arkansas.

Procedures

All small-plot trials were conducted at the University of Arkansas System Division of Agriculture's Rohwer Research Station, near Rohwer, Ark. on a silt-loam soil with 38-in. row-spacings and were inoculated. The inoculum was made from a field harvested isolate of the fungus that causes TRD, propagated on potato dextrose agar amended with an antibiotic, and then transferred to twice autoclaved millet. The infested millet was incubated at room temperature and shaken daily to disseminate spores for approximately 2 weeks then dried. The inoculum was planted with the seed at a rate of 0.5 g/row-ft using a plot planter. All trials were arranged in a randomized complete block design.

Determining the Distribution Across the Soybean Production Area in Arkansas. Images representative of field symptoms and signs were made available to county agents, farmers, and consultants via email, text groups, and Twitter to identify fields with TRD. Samples were collected to confirm the disease. Fields confirmed to have TRD were recorded by GPS location and marked on a larger regional map.

Determining Disease Severity on Commonly Planted Varieties. Varieties were planted into plots 2-rows wide and 10-ft long at a seeding rate of approximately 100 seed/row,

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replicated 3 times. Trials were planted on 3 May 2018 and 19 June 2019. Stand counts and percent emergence data were collected on 18 May 2018, and stand counts repeated 14 June 2018. In 2019, plant stand data were collected 10 July, and percent disease incidence and severity based on foliar expression were collected 19 Sept. To determine percent disease incidence and severity prior to harvest, ten plants per plot were dug, roots washed, and incidence of taproot decline determined on 13 Sept. 2018 and 9 Oct. 2019. Data were subjected to analysis of variance (ANOVA) followed by means separation of fixed effects using Fisher's protected least significant difference (LSD) at $P = 0.05$.

Determining the Efficacy of Seed Treatment Fungicides Against the Disease. A trial was planted in Asgrow 4632 on 4 May 2018. In 2019, Progeny P4757RY was planted 20 April. Six seed treatments and 5 in-furrow fungicides were planted into 4-row plots, 20-ft long and replicated 4 times. Plant stand data and percent emergence data were collected on 21 May 2018 and 14 May, 24 May, and 10 June in 2019. Prior to harvest, ten plants per plot were dug, roots washed, and incidence of taproot decline determined on 5 Sept. 2018 and 9 Oct. 2019. The trials were harvested on 19 Sept. 2018 and 9 Oct. 2019. Yields were adjusted to 13% moisture content for comparison. Data were subjected to analysis of variance followed by means separation of fixed effects using Fisher's protected least significant difference (LSD) at $P = 0.05$.

Determining the Field Distribution and Yield Impact of the Disease in the Field. One hundred points were marked by GPS in a representative area (1–2 acres) in a field with TRD. The number of diseased plants and stand losses was assessed at those points combined with georeferenced soil data from each location, modeled to determine incidence and severity and interpolated using ordinary kriging. Yield loss was estimated from correlations of incidence and severity of TRD, and farmer-provided georeferenced yield data. Data were processed and visualized in ArcMap (ESRI, Redlands, Calif.), and spatial correlations and aggregation statistics calculated in GeoDa (Center for Spatial Data Science, University of Chicago, Chicago, Ill.).

Results and Discussion

Determining the Distribution Across the Soybean Production Area in Arkansas. Taproot decline has been identified in 11 counties within the soybean production areas of Arkansas and is shown in Fig. 1.

Determining Disease Severity on Commonly Planted Varieties. Taproot decline was severe with significant stand loss throughout the test in 2018 and mild to moderate loss overall in 2019. In 2018, the change in stands ranged from an increase of 31 plants (Armor 48L30), resulting in a 56.5% emergence rate to a loss of 28 plants with GoSoy 5115LL, and the lowest emergence rate was 24% with GoSoy 5067LL in 2018. Varieties with a lesser incidence in the test were Hefty H47L5 and Progeny P4716LL. The difference in stands from 18 May and 14 June, percent emergence, and the greatest incidence for each treatment (to show the capability of the disease) at harvest are shown in Table 1. In 2019, P4757RY with the greatest emergence rate at 48% and R11-7999 with the least emergence rate at 1%. Plant stands observed on 10 July 2019, percent emergence, and the greatest individual plot incidence for each treatment are shown in Table 2.

Determining the Efficacy of Seed Treatment Fungicides Against the Disease. The seedling disease caused by the TRD fungus was severe, with significant stand loss throughout the test both years. In 2018, the only treatment that exhibited phytotoxicity was Topguard Terra®. Both Mertect® 340F (thiabendazole) at 0.64 oz/cwt and Stamina® (pyraclostrobin) at 1.5 fl oz/cwt performed numerically, and sometimes significantly, better than other products tested as well as the untreated controls depending on the variable measured. Topsin® (thiophanate-methyl) at 20 fl oz/ac also had positive results, having lesser incidence than many treatments and having a significantly higher yield than some treatments and the highest yield numerically. Plant stand data, percent emergence assessments, the greatest incidence for each treatment (in order to show the capability of the disease), and yield are shown in Table 3. In 2019, Topsin® treatment yielded significantly higher than all other treatments and was the only treatment to yield significantly higher than the untreated plots. These data, along with 10 June plant stands from both inoculated and uninoculated rows, percent emergence, greatest TRD incidence from each treatment, and yield are presented in Table 4.

Determining the Field Distribution and Yield Impact of the Disease in Fields. In a field near Eudora, Ark., TRD had a clustered distribution and correlated with spatial yield variability ($P = 0.05$). An example of the clustered nature of the TRD is shown in Fig. 2. Yield losses were estimated to be between 10–50 bu./ac at this location where TRD occurred. In Arkansas, TRD has been found as far north as Craighead County, and mean yield loss was determined to be approximately 30% on impacted plants. Additionally, some farmer and consultant reports indicate losses could be as high as 10 bu./ac in some fields.

Practical Applications

From these studies, it is evident that taproot decline can be a yield-limiting disease with economic implications. With data from varietal screens documenting TRD severity, and efficacy of various seed treatments, management plans can begin to be made; and combined with future data, it may be possible to minimize the impact of this disease.

Acknowledgments

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Table 1. Taproot decline varietal screening data from the University of Arkansas System Division of Agriculture's Rohwer Research Station, Rohwer, Ark., 2018.

Variety	14 June Plant Stands	Change in Stand 18 May to 14 June	% Emergence‡	Incidence 13 Sept. (0-10)
Armor 44L20	74.3	6.3 c-k†	37.2	8
Armor 48L30	63.5	31.0 k	31.8	7
CZ 4222 LL	52.5	0.5 b-j	52.5	6
CZ 4540 LL	84.0	21.0 h-k	42.0	5
CZ 4748 LL	83.5	0.0 b-j	41.8	6
CZ 5147 LL	74.5	12.5 d-k	37.3	8
CZ 5150 LL	55.0	-22.5 ab	27.5	5
CZ 5242 LL	71.5	6.0 c-k	35.8	6
Delta Grow DG4781 LL	83.3	-4.0 a-h	41.7	7
Delta Grow DG4967 LL	58.7	2.0 b-j	29.3	8
Delta Grow DG5067 LL	48.0	-23.0 ab	24.0	7
Dyna-Gro S45LL97	84.5	6.5 c-k	42.3	8
Dyna-Gro S49LL34	100.0	10.5 c-k	50.0	7
Dyna-Gro S55LS75	76.5	-4.5 a-h	38.3	6
GoSoy 43L16	76.7	16.3 f-k	38.3	10
GoSoy 49L17	62.3	7.0 c-k	31.2	10
GoSoy 5115LL	63.5	-28.0 a	31.8	10
GoSoy 56C16	74.3	-12.7 a-d	37.2	10
GoSoy Ireane	56.0	5.5 c-k	28.0	5
GoSoy Leland	78.7	6.0 abc	39.3	9
HBK LL 4950	79.7	-0.7 b-j	39.8	7
HBK LL 4953	75.0	-9.3 a-f	37.5	7
Hefty H47L5	98.5	22.0 ijk	49.3	4
Hefty H48L3	93.0	16.5 g-k	46.5	5
JTN-5110	87.7	-6.0 a-g	43.8	7
Osage	74.5	9.0 c-k	37.3	7
Pfister 48RS01	85.7	-6.7 a-g	42.8	8
Pioneer P50T78L	77.7	6.0 c-k	38.8	6
Progeny P4247LL	79.7	-6.3 a-g	39.8	8
Progeny P4716LL	70.5	-0.5 b-j	35.3	4
Progeny P4930LL	63.5	-9.0 a-g	31.8	5
Progeny P5414LLS	92.0	7.7 c-k	46.0	9
Progeny P5623LL	66.7	-7.3 a-g	33.3	7
REV 45L57	80.7	-3.0 a-i	40.3	6
REV 48A26	70.0	-13.0 d-k	35.0	9
REV 48L63	75.3	-6.7 a-g	37.7	8
REV 49L88	88.5	-10.0 c-k	44.3	8
S13-10590C	81.5	6.5 c-k	40.8	7
S13-1805C	99.0	-7.0 c-k	49.5	5
S14-6391C	78.5	16.0 f-k	39.3	5
UA 5014C	61.0	-15.0 abc	30.5	10
UA 5814HP	94.0	10.0 c-k	47.0	7
USG Ellis	69.5	10.5 c-k	34.8	7

†Columns followed by the same letter are not statistically significant at $P = 0.05$ as determined by Fisher's protected least significant difference test.
‡Percent emergence calculated by dividing plant stand by planting rate.

Table 2. Taproot decline varietal screening data from the University of Arkansas System Division of Agriculture's Rohwer Research Station, Rohwer, Ark., 2019.

Variety	10 July Plant Stand	Emergence‡	Greatest Plot Incidence 10 Oct. (0-10)§
		%	
AG46X6	15.7 jk†	7.8 jk	8
AG47X6	76.7 abc	38.3 abc	6
AG53X6	42.3 e-h	21.2 e-h	9
Croplan 5265	3.3 k	1.7 k	0
DG4967LL	67.3 cd	33.7 cd	4
DG5580	60.3 cde	30.2 cde	4
Dyna-Gro 39RY43	75.3 abc	37.7 abc	7
LA560512	22.3 h-k	11.2 h-k	6
Osage	45.0 efg	22.5 efg	4
P4757RY	95.3 a	47.7 a	4
R09-430	56.0 c-f	28.0 c-f	4
R09-1589	57.7 a-f	28.8 c-f	5
R10-197RY	60.3 a-f	30.2 cde	6
R11-89RY	76.0 abc	38.0 abc	4
R11-7999	1.3 k	0.7 k	5
R13-1019	92.0 ab	46.0 ab	8
REV 56R63	77.7 abc	38.8 abc	6
S11-17025	63.0 cde	31.5 cde	5
S11-20124	71.3 bc	35.7 bc	5
S11-20337	48.3 d-g	24.2 d-g	3
S12-2418	37.7 f-i	18.8 f-i	3
S12-3782	17.3 ijk	8.7 ijk	8
UA 5014C	57.7 a-f	28.8 c-f	5
UA 5213C	71.0 a-d	35.5 bc	7
UA 5414RR	33.7 g-j	16.8 g-j	5
UA 5612	60.7 a-f	30.3 cde	4
UA 5615C	28.3 d-g	14.2 g-j	5
UA 5715GT	56.0 a-f	28.0 c-f	2
UA 5814HP	21.7 efg	10.8 h-k	3

†Columns followed by the same letter are not statistically significant at $P = 0.05$ as determined by Fisher's protected least significant difference test.
‡Percent emergence calculated by dividing plant stand by planting rate.
§Highest single plot incidence rating from the replicated plots.

Table 3. Fungicide seed treatment efficacy against taproot decline from the University of Arkansas System Division of Agriculture's Rohwer Research Station, Rohwer, Ark., 2018.

Treatment and Rate	Plant Stand 21 May	Emergence 21 May‡	Greatest Incidence 5 Sept. (0-10)	Yield§
		%		bu./ac
Acquire® 0.75 fl oz/cwt	102.3 ab†	55.0 ab	10	41.8 bc
Headline® 10.8 fl oz/ac	85.3 b	43.8 b	10	44.2 ab
Ilevo® 2 fl oz/cwt	90.8 b	41.3 b	8	47.3 ab
Mertect® 0.64 fl oz/cwt	134.3 a	68.8 a	8	50.5 ab
Ridomil® 3.7 fl oz/ac	83.5 b	45.0 b	8	42.2 b
Sercadis® 4.4 fl oz/ac	102.3 ab	57.5 ab	8	49.6 ab
Stamina® 1.5 fl oz/cwt	141.8 a	70.0 a	9	50.8 ab
Topguard Terra® 8 fl oz/ac	24.8 c	15.3 c	4	27.0 c
Topsin® 20 fl oz/ac	108.8 ab	55.0 ab	5	58.8 a
Untreated	107.3 ab	57.5 ab	9	41.0 bc
Vibrance® 0.16 fl oz/cwt	102.0 ab	53.8 ab	5	40.9 bc
Vortex® 0.17 fl oz/cwt	116.5 ab	55.0 ab	9	43.5 b

†Columns followed by the same letter are not statistically significant at $P = 0.05$ as determined by Fisher's protected least significant difference test.
‡Percent emergence calculated by dividing plant stand by planting rate.
§Yields adjusted to 13% moisture content for comparison.

Table 4. Fungicide seed treatment efficacy against taproot decline from the University of Arkansas System Division of Agriculture's Rohwer Research Station, Rohwer, Ark., 2019.

Treatment and Rate	Plant Stand 10 June Uninoculated	Plant Stand 10 June Inoculated	Emergence 10 June‡	Greatest Incidence 19 Sept. (0-10)	Yield§
			%		bu./ac
Acquire® 0.75 fl oz/cwt	96 b†	18	19.4 bcd	10	14.9 bc
Headline® 10.8 fl oz/ac	100 ab	34	34.0 abc	10	10.0 cd
Ilevo® 2 fl oz/cwt	84 bcd	12	11.8 de	10	13.7 bcd
Mertect® 0.64 fl oz/cwt	98 b	20	19.5 bcd	10	17.9 b
Ridomil® 3.7 fl oz/ac	62 d	26	41.7 a	9	12.2 bcd
Sercadis® 4.4 fl oz/ac	124 a	18	15.1 de	10	18.3 b
Stamina® 1.5 fl oz/cwt	102 ab	14	13.2 de	10	17.7 b
Topguard Terra® 8 fl oz/ac	104 ab	0	0.0 de	10	6.7 d
Topsin® 20 fl oz/ac	88 bc	26	28.9 a-d	10	29.7 a
Untreated	82 bcd	12	13.7 de	10	11.1 bcd
Vibrance® 0.16 fl oz/cwt	94 b	14	15.5 cde	10	9.5 cd
Vortex® 0.17 fl oz/cwt	64 cd	24	37.1 ab	10	16.2 bc

†Columns followed by the same letter are not statistically significant at $P = 0.05$ as determined by Fisher's protected least significant difference test.
‡Percent emergence calculated by dividing stands from inoculated rows by stands from uninoculated rows.
§Yields adjusted to 13% moisture content for comparison.

Determining Management Strategies for Diseases and Disease-Causing Microorganisms that Impact Soybean Quality, 2019

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Abstract

To determine the impact of disease and stinkbug feeding on soybean grain quality, replicated fungicide trials were placed at the University of Arkansas System Division of Agriculture's Rohwer Research Station and the Vegetable Research Station near Rohwer and Kibler, Ark., respectively, on two varieties (CZ4105 and CZ4748) using 4 fungicide treatments at 3 timings with untreated controls included. Pods were selected prior to harvest, seed removed, and pods and seed plated in agar filled Petri dishes to determine the pathogens present. Pods were also selected from a variety trial located at Rohwer Research Station and plated in the same manner as above. All pods and seed were observed for stink bug damage, but none was found. The Kibler location had differences in foliar disease ratings, yield, and *Cercospora* colonies produced from seed. The CZ4105 variety had lower amounts of purple seed stain in all treatments where an R5 application alone was applied (except for propiconazole). The CZ4748 variety at Kibler had a high incidence of Bacillus seed decay, reported to be caused by *Bacillus subtilis* across all treatments, which was not found in other trials. Numerical averages were determined for varieties from the trial at Rohwer with higher amounts of *Phomopsis* spp. and purple seed stain in some varieties.

Introduction

Seed quality can be impacted significantly by insect damage and fungal infestations. Stink bugs are common in Arkansas soybean production, where both adults and nymphs feed on soybean pods and seed. These insects feeding on premature seed can cause yield loss by initiating pod/seed abortions or seed size reduction. Quality reduction is also caused by digestive fluids entering seed during feeding, which leads to deterioration and discoloration of seed. (Lorenz et al., 2000)

Common fungal diseases that impact grain quality include purple seed stain (PSS) and Phomopsis seed decay. Purple seed stain is caused by multiple species of fungi in the genus *Cercospora* that stain the seed coat purple. This disease has not been associated with yield loss but can cause significant reduction in grain quality by causing reduced vigor and increased seed decay and discoloration (Alloatti et al., 2015). Phomopsis seed decay caused by *Phomopsis longicolla* can cause deformed, split, or moldy grain, altering seed viability and oil composition (Li et al., 2010).

Also found in this study was *Bacillus subtilis*, a bacterium that causes Bacillus seed decay and produces a slimy coat causing an often-wrinkled appearance that is most often found in seed assays but can occur in the field. *Bacillus subtilis* is ubiquitous and survives in the soil, and some strains are used as a biological seed treatment due to the antifungal secretions that they produce (Cubeta and Hartman, 1985).

These diseases are favored by the hot, humid conditions we consistently experience in Arkansas each year and survive on crop debris and in field soil. The objective of this work was to determine the impact of soybean variety and fungicide efficacy and timing on diseases that reduce seed quality. Additionally, this work seeks to determine the interactions of these diseases with stink bug feeding when opportunities to collect those data are available.

Procedures

In 2019, identical trials were established at the University of Arkansas System Division of Agriculture's Rohwer Research Station and the Vegetable Research Station near Rohwer and Kibler, Ark., respectively. Each location had two trials with one planted to CZ4105 and the other to CZ4748. Plots were 4-rows wide and 25-ft long on 38-in. row-spacings. Treatments included an untreated control and 4 fungicide treatments applied at R3, R3 + R5, and R5 for a total of 13

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treatments in 5 replications. Fungicides applied were Headline© (pyraclostrobin) 12 fl oz/ac, Priaxor© (fluxapyraoxad + pyraclostrobin) 8 fl oz/ac, Tilt© (propiconazole) 6 fl oz/ac, and Topsin-M© (thiophanate-methyl) 1lb/ac. All fungicides were applied in a total water volume of 15 gal/ac using TeeJet VS11002 spray tips. Foliar disease severity ratings were based on a 0–10 scale where disease severity 0 = no disease and 10 = dead plants. Rohwer Station trials were planted 11 June at a seeding rate of 110,000 seed/ac, fungicides were applied on 5 and 28 Aug., foliar ratings recorded on 4 Sept., and both trials were harvested 10 Oct. Trials at Kibler were planted 17 June at 116,000 seed/ac, fungicides applied 10 and 29 Aug., plots assessed for foliar diseases on 13 Sept. and 1 Oct., and plots harvested 4 Oct. (CZ4105) and 4 Nov. (CZ4748).

Prior to harvest, 10 pods per plot were collected from the tops of the canopy and placed in an envelope, sealed, and labeled according to plot number. The envelopes were then placed into a standard refrigerator and kept until processed. At the time of processing, the pods were opened, seed extracted, separated, and observed for stink bug damage. Each pod and seed were surface disinfested using a 3:1 95% ethanol to distilled water solution for 30 seconds, air-dried, and plated on sterile half-strength potato dextrose agar amended with 0.25g/L ampicillin sodium salt and 500uL/L potassium phosphite in a standard-sized Petri dish. Pods were plated 1 per Petri dish and seed five per Petri dish. Petri dishes were labeled and allowed to incubate for 10 days in ambient laboratory conditions, at which time fungal colonies were categorized and quantified. All data were subjected to analysis of variance (ANOVA), followed by means separation of fixed effects using Fisher's protected least significant difference (LSD) at $P = 0.10$. Yield data were adjusted to 13% moisture content for comparison.

Pods were also taken from a variety trial to determine if any differences existed amongst varieties. In order to determine pathogen presence, pods and seed were processed using the method described in the previous paragraph. However, this test had three replications of each variety that were combined, mixed thoroughly, and 10 pods arbitrarily selected for the assay. Replicated foliar ratings and yields have been added to the results tables for reference. Disease severity was rated as previously described, and data were subjected to ANOVA followed by means separation as determined by Tukey's honestly significant difference test at $P = 0.10$.

Results and Discussion

Fungicide trials at Rohwer had no differences in any measured variable. In the CZ4105 trial, *Phomopsis* spp. were found in pod tissue an average of 14.4% (6.8–23.6%) and in 0.7% (0–2.4%) of seed. *Cercospora* spp. were found in pod tissue an average of 0.9% (0.0–3.4%) and in 14.6% (10.6–21.8%) of seed. Foliar rating of target spot averaged 3.3 (2.4–5.0) on a scale of 0–10. Yields averaged 47.9 (46.2–48.1) bu./ac. In the CZ4748 trial, *Phomopsis* spp. were found on an average of 35.8% (24.6–56.6%) of pods and 0.5% (0.0–1.8%) of seed. *Cercospora* spp. were found on an average of 0.2% (0.0–2.0%) pods and 4.6% (0.6–9.2%) seed. Foliar rating of target spot averaged 2.4 (1.0–3.4) on a scale of 0–10. Yields averaged 50.94 (46.2–54.3) bu./ac.

The Kibler trial data for CZ4105 treatments are shown in Table 1. *Phomopsis* spp. were found on an average of 15.3% (4.0–24.2%) of pods and 5.2% (2.2–10.8%) of seed. *Cercospora* spp. were found on an average of 0.2% (0.0–2.0%) pods and 14.0% (6.2–23.6%) seed. Seed producing colonies of Cercospora spp. were fewer among those treated at R5 except for Tilt©. Foliar rating of target spot averaged 3.9 (1.3–5.8) on a scale of 0–10. Target spot was found in lesser amounts in Headline© and Priaxor© plots applied at R3 + R5. Yields averaged 48.9 (43.1–55.0) bu./ac. All treatments yielded greater than the untreated except for Tilt© and Topsin© applied at R3, and Headline© applied at R5.

The Kibler CZ4748 treatment data are shown in Table 2. *Phomopsis* spp. were found on an average of 2.9% (0.0–10.0%) of pods and 0.6% (0.0–2.4%) of seed. *Cercospora* spp. were absent on pods and averaged 0.6% (0.0–4.8%) on seed. Bacillus seed decay was found on an average of 91.7% (80.2–98.4%), which is an antagonist of other fungi observed in this study, and likely prevented colony growth. Foliar ratings of target spot averaged 3.0 (1.6–5.0) on a scale of 0–10. Target spot severity was greater in the Tilt© R3 treatment than the untreated and lesser in Headline© R3 and R3 + R5 and Priaxor© R3 + R5 and R5 treatments. Foliar ratings of Cercospora leaf blight averaged 1.8 (1.0–2.8) on a scale of 0–10. Treatments of Headline©, Priaxor©, and Tilt© applied at R3 + R5 and Headline© and Priaxor© applied at R3 performed better than the untreated. Yields averaged 55.9 (50.0–60.3) bu./ac.

The variety trial sampling was not replicated, therefore only numerical averages are available. The varieties are divided by maturity groups, and data can be observed in Tables 3–7. Stink bug activity was low in each trial, and damage to sampled seed was either minimal or not observed in trials.

Practical Applications

The data collected from these trials combined with future data will help to determine the impact variety, stink bugs, and pathogens have on grain quality individually as well as when compounded. These results will help provide best management practices to producers by providing varietal quality data, and best timings for pesticide applications, and when those applications are warranted.

Acknowledgments

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Table 1. Fungicide trial planted in CZ4105 at the Vegetable Research Station near Kibler, Arkansas Treatments, growth stage applied, and percent pods (out of 10) and seed (out of 25) that when plated produced fungal colonies, and foliar disease severity ratings based on a 0–10 scale, where 0 = no disease, and 10 = dead plants.

		Pods		Seed		Foliar	
Treatment and rate/ac	Growth Stage	Phomopsis	PSS†	Phomopsis	PSS†	TS†	Yield§
Headline 2.08 SC 12 fl oz	R3	15.0	0.0	7.2	15.0 abc‡	2.3 cde	55.0 a
Headline 2.08 SC 12 fl oz	R3+R5	20.0	0.0	2.4	10.0 c	1.3 e	53.2 ab
Headline 2.08 SC 12 fl oz	R5	8.0	0.0	10.2	6.2 c	3.8 a-d	47.2 cde
Priaxor 4.17 SC 8 fl oz	R3	14.0	0.0	6.4	15.6 abc	2.7 b-e	48.5 bcd
Priaxor 4.17 SC 8 fl oz	R3+R5	24.2	2.0	4.8	14.4 abc	1.5 de	54.7 a
Priaxor 4.17 SC 8 fl oz	R5	24.0	0.0	2.2	9.2 c	4.5 abc	50.3 abc
Tilt 3.6 EC 6 fl oz	R3	22.0	0.0	2.2	20.8 ab	5.5 a	47.5 cde
Tilt 3.6 EC 6 fl oz	R3+R5	12.2	0.0	10.8	14.4 abc	4.5 abc	45.0 de
Tilt 3.6 EC 6 fl oz	R5	21.2	0.0	7.2	13.2 bc	5.0 ab	47.2 cde
Topsin-M 70 WP 1 lb	R3	10.0	0.0	3.0	23.6 a	5.8 a	46.7 cde
Topsin-M 70 WP 1 lb	R3+R5	16.0	0.0	3.2	12.0 bc	4.8 ab	48.0 cd
Topsin-M 70 WP 1 lb	R5	8.2	0.0	4.2	6.6 c	4.8 ab	49.3 bcd
Untreated	N/A	4.0	0.0	3.6	21.2 ab	4.5 abc	43.1 e

† PSS = Purple seed stain (*Cercospora* spp.); TS = Target Spot (*Corynespora cassiicola*); CLB = Cercospora leaf blight (*Cercospora* spp.).

‡ Columns followed by the same letter are not statistically significant at P = 0.10 as determined by Fisher's protected least significant difference (LSD) test.

§ Yield (bu./ac) adjusted to 13%.

Table 2. Fungicide trial planted in CZ4748 at the Vegetable Research Station near Kibler, Ark. Treatments, growth stage applied, and percent pods (out of 10) and seed (out of 25) that when plated produced fungal colonies of known pathogens, and foliar disease severity ratings based on a 0–10 scale, where 0 = no disease, and 10 = dead plants.

		Pods		Seed		Foliar		
Treatment and rate/ac	Growth Stage	Phomopsis	PSS†	Phomopsis	PSS	TS†	CLB†	Yield§
Headline 2.08 SC 12 fl oz	R3	0.0	0.0	0.0	0.0	2.0 de‡	2.0 bc	59.5
Headline 2.08 SC 12 fl oz	R3+R5	2.0	0.0	0.0	4.8	1.6 e	1.4 cd	60.3
Headline 2.08 SC 12 fl oz	R5	10.0	0.0	0.0	1.6	1.8 e	1.0 d	60.3
Priaxor 4.17 SC 8 fl oz	R3	0.0	0.0	0.8	3.0	1.8 e	2.2 ab	55.3
Priaxor 4.17 SC 8 fl oz	R3+R5	2.0	0.0	1.4	0.0	1.8 e	1.0 d	53.1
Priaxor 4.17 SC 8 fl oz	R5	0.0	0.0	0.8	1.6	3.0 cde	1.0 d	55.8
Tilt 3.6 EC 6 fl oz	R3	6.0	0.0	0.0	0.6	5.0 a	2.2 ab	50.0
Tilt 3.6 EC 6 fl oz	R3+R5	0.0	0.0	0.8	3.2	3.8 abc	1.4 cd	58.4
Tilt 3.6 EC 6 fl oz	R5	6.0	0.0	0.0	0.0	3.0 cde	1.8 bc	51.4
Topsin-M 70 WP 1 lb	R3	4.0	0.0	0.8	3.4	4.8 ab	2.8 a	55.6
Topsin-M 70 WP 1 lb	R3+R5	6.0	0.0	2.4	0.0	2.8 cde	2.0 bc	54.6
Topsin-M 70 WP 1 lb	R5	0.0	0.0	0.8	0.0	4.6 ab	2.2 ab	53.8
Untreated	N/A	2.0	0.0	0.0	0.0	3.4 bcd	2.2 ab	59.0

† PSS = Purple seed stain (*Cercospora* spp.); TS = Target Spot (*Corynespora cassiicola*); CLB = Cercospora leaf blight (*Cercospora* spp.).

‡ Columns followed by the same letter are not statistically significant at P = 0.10 as determined by Fisher's protected least significant difference (LSD) test.

§ Yield (bu./ac) adjusted to 13%.

Table 3. Soybean maturity groups (MG) 3.8–4.5 percent pods (out of 10) and seed (out of 25) that when plated produced colonies of known pathogens, and foliar disease severity ratings based on a scale, where 0 = no disease, and 100 = dead plants.

			Pod	Seed		Foliar		
Variety	**MG**	**Tech**	**Phom.†**	**Phom.†**	**PSS†**	**TS†**	**CLB†**	**Yield§**
Credenz CZ3841LL	3.8	LL	70	0	7	0.0 e‡	0.0 c	35.0 hi
Credenz CZ3929GTLL	3.9	GT/LL	0	0	5	1.0 de	7.3 bc	84.5 a-h
Local LS3976X	3.9	Xtend	67	0	0	0.0 e	n/a	73.5 a-i
NK S39-G2X	3.9	Xtend	30	0	0	0.0 e	n/a	62.2 b-i
Dyna-Gro S41XS98	4.1	Xtend/STS	50	0	9	0.0 e	0.0 c	60.8 b-i
S13-2743C	4.1	Conv.	20	0	7	0.0 e	5.0 bc	n/a
Armor 42-D27	4.2	Xtend	40	4	8	0.0 e	0.3 c	80.7 a-h
Asgrow AG42X9	4.2	Xtend	67	20	12	0.0 e	3.7 bc	67.6 a-i
Credenz CZ4222LL	4.2	LL	90	0	10	0.0 e	0.0 c	68.9 a-i
Credenz CZ4280X	4.2	Xtend	30	0	12	0.0 e	3.7 bc	88.8 a-h
Dyna-Gro S42EN89	4.2	Enlist	20	4	4	2.3 cde	8.3 bc	81.4 a-h
Local LSX4301XS	4.2	Xtend	70	4	0	0.0 e	6.7 bc	80.0 a-i
Pioneer P42A96X	4.2	Xtend	60	0	24	0.0 e	10.3 bc	84.4 a-h
Progeny P4241 E3	4.2	E3	20	0	12	0.0 e	0.0 c	56.4 b-i
Progeny P4255RX	4.2	Xtend	80	0	7	0.0 e	3.3 bc	91.0 a-g
Progeny P4265RXS	4.2	Xtend/STS	60	0	4	0.0 e	10.0 bc	76.7 a-i
Progeny P4291LR	4.2	LL/GT27	20	0	0	2.0 cde	1.3 bc	86.3 a-h
Asgrow AG43X0	4.3	Xtend	50	0	4	0.3 de	0.3 c	74.9 a-i
REV4310X	4.3	Xtend	40	0	0	0.0 e	1.0 bc	85.5 a-h
AgriGold G4440RX	4.4	Xtend	60	0	4	0.0 e	3.7 bc	91.9 a-g
Armor 44-D92	4.4	Xtend	30	0	4	0.3 de	1.3 bc	79.0 a-i
Delta Grow 45E23	4.4	E3	30	0	0	0.0 e	0.0 c	57.9 b-i
Eagle Seed ES4460RYX	4.4	Xtend	30	0	0	0.0 e	14.0 bc	80.4 a-i
Local LS4487XS	4.4	Xtend	30	0	4	0.7 de	7.0 bc	79.2 a-i
Mission A4448X	4.4	Xtend	30	0	0	0.3 de	1.0 bc	91.8 a-g
MorSoy 4447 RXT	4.4	Xtend	10	4	8	0.7 de	5.7 bc	96.1 a-g
NK S44-C7X	4.4	Xtend	20	0	0	0.3 de	10.3 bc	90.5 a-h
Progeny P4444RXS	4.4	Xtend/STS	13	0	0	0.0 e	0.7 bc	85.9 a-h
S13-3851C	4.4	Conv.	20	0	10	0.0 e	1.0 bc	49.9 c-i
AgriGold G4579RX	4.5	Xtend	60	8	4	0.3 de	7.3 bc	97.4 a-g
Armor X45D51	4.5	Xtend	80	13	7	0.0 e	1.3 bcd	96.5 a-f
Credenz CZ4539GTLL	4.5	GT/LL	30	0	0	2.3 cde	0.7 cd	97.4 a-g
Credenz CZ4540LL	4.5	LL	50	3	0	0.0 e	1.0 bc	82.8 a-h
Credenz CZ4570X	4.5	Xtend	60	0	4	0.0 e	2.7 bc	88.4 a-h
Dyna-Gro S45XS37	4.5	Xtend/STS	80	4	0	0.0 e	6.7 bc	91.4 a-g
Dyna-Gro S45XS66	4.5	Xtend/STS	40	8	0	0.3 de	10.0 bc	97.1 a-f
Local LS4565XS	4.5	Xtend	70	7	4	0.0 e	1.3 bc	83.8 a-h
Local LS4583X	4.5	Xtend	30	0	7	0.0 e	0.3 c	74.6 a-i
Local LSX4501X	4.5	Xtend	50	0	4	0.0 e	0.3 c	85.0 a-h
Local LSX4503GTLL	4.5	GT/LL	30	0	0	1.0 de	3.7 bc	85.0 a-h
Progeny P4525 E3	4.5	E3	44	4	12	2.0 cde	1.5 bc	41.6 f-i
Progeny P4565LR	4.5	LL/GT27	11	0	4	1.0 de	2.3 bc	100.1 a-e

† Phom. = *Phomopsis* spp.; PSS = Purple seed stain (*Cercospora* spp.); TS = Target Spot (*Corynespora cassiicola*); CLB = Cercospora leaf blight (*Cercospora* spp.).

‡ Foliar disease severity ratings and yield columns followed by the same letter are not statistically significant at $P = 0.10$ as determined by Tukey's honestly significant difference test.

§ Yield (bu./ac) adjusted to 13%.

Table 4. Soybean maturity groups (MG) 4.6–4.7 percent pods (out of 10) and seed (out of 25) that when plated produced colonies of known pathogens, and foliar disease severity ratings based on a scale, where 0 = no disease, and 100 = dead plants.

			Pod	Seed		Foliar		
Variety	MG	Tech	Phom.†	Phom.†	PSS†	TS†	CLB†	Yield§
AgriGold G4605RX	4.6	Xtend	70	0	0	0.0 e‡	6.7 bc	74.6 a-i
Armor X46D09	4.6	Xtend	50	0	14	0.0 e	7.3 bc	98.2 a-e
Armor X46D30	4.6	Xtend	40	0	3	0.3 de	21.7 ab	98.2 a-e
Asgrow AG46X0	4.6	Xtend	67	0	8	0.0 e	7.0 bc	69.1 a-i
Asgrow AG46X6	4.6	Xtend	60	0	4	0.0 e	3.3 bc	90.0 a-h
Credenz CZ4600X	4.6	Xtend	40	3	0	0.7 de	1.0 bc	63.0 b-i
Credenz CZ4649LL	4.6	LL	0	0	4	0.0 e	5.0 bc	88.0 a-h
Delta Grow 46E29	4.6	E3/STS	33	0	4	0.7 de	0.3 c	50.5 c-i
Delta Grow 46X25	4.6	Xtend	50	0	0	0.0 e	1.0 bc	99.3 a-e
Delta Grow 46X65	4.6	Xtend/STS	30	0	0	0.0 e	1.0 bc	74.1 a-i
Dyna-Gro S46EN29	4.6	Enlist	10	0	4	2.3 cde	1.0 bc	87.3 a-h
Dyna-Gro S46XS60	4.6	Xtend/STS	0	0	0	0.3 de	2.3 bc	69.0 a-i
Eagle Seed ES4680RYX	4.6	Xtend	30	0	0	0.0 e	0.0 c	77.4 a-i
Go Soy 46GL18	4.6	LL/GT27	10	0	4	1.0 de	1.0 bc	63.9 a-i
Hefty H46X0S	4.6	Xtend	50	0	0	0.3 de	1.0 bc	90.2 a-h
LGS4420RX	4.6	Xtend	0	0	0	0.7 de	0.3 c	73.0 a-i
Local LS4677X	4.6	Xtend	40	3	7	0.0 e	17.0 abc	71.0 a-i
Local LSX4601XS	4.6	Xtend	20	0	8	0.3 de	0.3 c	88.8 a-h
Local LSX4602ES	4.6	Xtend	30	0	13	1.0 de	2.3 bc	104.5 a-c
Mission A4618X	4.6	Xtend	50	4	9	0.7 de	2.0 bc	60.7 b-i
Pioneer P46A57BX	4.6	Xtend	40	4	12	1.7 de	10.3 bc	83.9 a-h
Progeny P4620RXS	4.6	Xtend/STS	40	13	10	1.0 de	36.7 a	62.0 b-i
Progeny P4670RX	4.6	Xtend	30	4	8	0.0 e	1.0 bc	89.2 a-h
Progeny P4682 E3	4.6	E3	30	5	15	1.7 de	0.3 c	44.9 e-i
R16-253	4.6	Conv.	40	0	8	0.0 e	2.7 bc	118.8 a
R16-259	4.6	Conv.	30	0	0	0.0 e	4.0 bc	59.4 b-i
REV 4679X	4.6	Xtend	50	0	0	0.0 e	20.3 abc	103.3 a-d
USG 7460ET	4.6	Enlist	30	0	32	2.3 cde	1.0 bc	82.0 a-h
Armor X47D18	4.7	Xtend	40	0	4	0.0 e	1.3 bc	93.7 a-g
Armor X47D85	4.7	Xtend	60	3	7	0.3 de	2.3 bc	74.8 a-i
Armor X47D86	4.7	Xtend	30	0	3	0.3 de	1.7 bc	92.0 a-g
Asgrow AG47X0	4.7	Xtend	40	0	28	0.0 e	1.0 bc	84.6 a-h
Asgrow AG47X9	4.7	Xtend	20	0	36	0.7 de	2.3 bc	72.5 a-i
Credenz CZ4770X	4.7	Xtend	30	0	0	2.0 cde	4.0 bc	99.6 a-e
Delta Grow 47E19	4.7	E3	0	0	4	0.0 e	1.5 bc	79.5 a-i
Delta Grow 47E25	4.7	E3	10	0	16	0.0 e	1.0 bc	74.3 a-i
DM 47X01	4.7	Xtend	20	0	4	1.0 de	4.3 bc	84.9 a-h
Dyna-Gro S47XT20	4.7	Xtend	50	0	17	0.3 de	2.3 bc	92.9 a-g
Local LS4798X	4.7	Xtend	20	0	28	1.7 de	14.0 bc	86.1 a-h
Local LSX4701E	4.7	Enlist	40	4	0	5.0 bcd	7.0 bc	90.7 a-h
MorSoy 4706 RXT	4.7	Xtend	40	0	0	0.7 de	1.3 bc	95.5 a-g
Progeny P4710 E3	4.7	E3	0	0	4	0.3 de	1.0 bc	68.1 a-i
Progeny P4775 E3S	4.7	E3/STS	18	5	0	3.7 b-e	1.3 bc	55.1 b-i
Progeny P4799RXS	4.7	Xtend/STS	40	0	4	0.3 de	0.7 bc	73.3 a-i
R15-2422	4.7	Conv.	20	0	0	0.0 e	1.7 bc	62.5 b-i
USG 7470XT	4.7	Xtend	20	0	27	0.3 de	1.0 bc	88.3 a-h
USG 7478XTS	4.7	Xtend/STS	30	0	7	0.0 e	4.0 bc	76.6 a-i

† Phom. = *Phomopsis* spp.; PSS = Purple seed stain (*Cercospora* spp.); TS = Target Spot (*Corynespora cassiicola*); CLB = Cercospora leaf blight (*Cercospora* spp.).

‡ Foliar disease severity ratings and yield columns followed by the same letter are not statistically significant at *P* = 0.10 as determined by Tukey's honestly significant difference test.

§ Yield (bu./ac) adjusted to 13%.

Table 5. Soybean maturity group (MG) 4.8 percent pods (out of 10) and seed (out of 25) that when plated produced colonies of known pathogens, and foliar disease severity ratings based on a scale, where 0 = no disease, and 100 = dead plants.

			Pod	Seed		Foliar		
Variety	MG	Tech	Phom.†	Phom.†	PSS†	TS†	CLB†	Yield§
AgriGold G4815RX	4.8	Xtend	30	0	0	2.0 cde‡	1.0 bc	47.7 d-i
AGS GS48X19	4.8	Xtend	10	0	20	0.7 de	0.7 bc	81.9 a-h
Armor X48D25	4.8	Xtend	30	7	17	1.3 de	0.7 bc	69.2 a-i
Armor X48D88	4.8	Xtend	50	0	5	2.7 cde	7.0 bc	69.6 a-1
Asgrow AG48X9	4.8	Xtend	20	0	10	1.3 de	1.0 bc	61.1 b-i
Credenz CZ4820LL	4.8	LL	56	20	0	8.3 ab	7.3 bc	75.2 a-i
Credenz CZ4869X	4.8	Xtend	80	0	12	1.0 de	1.3 bc	48.2 d-i
Delta Grow 48E10	4.8	E3	33	0	0	2.0 cde	3.7 bc	46.4 e-i
Delta Grow 48E39	4.8	E3	20	0	0	2.3 cde	2.3 bc	56.5 b-i
Delta Grow 48E49	4.8	E3/STS	33	0	0	5.0 bcd	1.3 bc	94.0 a-g
Delta Grow 48X45	4.8	Xtend	40	0	0	1.0 de	1.0 bc	40.5 ghi
DM 48E01	4.8	Enlist	50	0	0	1.0 de	11.7 bc	59.8 b-i
Dyna-Gro S48XT56	4.8	Xtend	20	0	7	1.3 de	1.0 bc	67.7 a-i
Eagle Seed ES4840RYX	4.8	Xtend	50	0	0	2.3 cde	4.0 bc	63.1 a-i
Go Soy 481E19	4.8	E3	20	0	4	0.3 de	1.7 bc	54.2 b-i
Go Soy 482E18	4.8	E3	50	0	0	4.0 b-e	15.0 abc	75.4 a-i
Go Soy 48C17S	4.8	Conv.	60	0	5	0.0 e	1.7 bc	24.8 i
Hefty H48E0	4.8	E3	30	0	4	2.3 cde	2.3 bc	107.4 ab
Hefty H48E9	4.8	E3	50	16	4	2.3 cde	15.0 bc	86.4 a-h
LGC4845RX	4.8	Xtend	11	0	4	1.0 de	2.3 bc	90.2 a-h
LGS4899RX	4.8	Xtend	30	0	4	3.3 cde	1.0 bc	58.3 b-i
Local LS4889XS	4.8	Xtend	30	0	4	1.0 de	0.3 c	79.2 a-i
Local LSX4801X	4.8	Xtend	0	0	0	0.7 de	1.3 bc	63.0 b-i
MorSoy 4846 RXT	4.8	Xtend	20	0	12	2.3 cde	2.3 bc	62.7 b-i
Pioneer P48A60X	4.8	Xtend	55	0	4	2.3 cde	0.3 c	67.5 a-i
Pioneer P48A99L	4.8	LL	60	0	8	10.0 a	8.7 bc	71.6 a-i
Progeny P4816RX	4.8	Xtend	10	0	8	1.0 de	1.0 bc	66.8 a-i
Progeny P4821RX	4.8	Xtend	20	0	0	2.0 cde	1.0 bc	61.7 b-i
Progeny P4833 E3	4.8	E3	0	0	0	3.7 b-e	4.0 bc	86.3 a-h
Progeny P4851RX	4.8	Xtend	30	0	16	1.0 de	0.7 bc	79.6 a-i
Progeny P4891 E3	4.8	E3	20	12	16	0.7 de	4.0 bc	94.0 a-g
S14-15138R	4.8	RR1/STS	20	0	10	0.7 de	1.0 bc	82.0 a-h
USG 7480ET	4.8	Enlist	30	0	0	3.7 b-e	10.3 bc	70.1 a-i
USG 7480XT	4.8	Xtend	30	0	0	1.0 de	1.0 bc	61.8 b-i
USG 7489XT	4.8	Xtend	0	0	12	1.0 de	0.7 bc	71.2 a-i

† Phom. = *Phomopsis* spp.; PSS = Purple seed stain (*Cercospora* spp.); TS = Target Spot (*Corynespora cassiicola*); CLB = Cercospora leaf blight (*Cercospora* spp.).
‡ Foliar disease severity ratings and yield columns followed by the same letter are not statistically significant at *P* = 0.10 as determined by Tukey's honestly significant difference test.
§ Yield (bu./ac) adjusted to 13%.

Table 6. Soybean maturity groups (MG) 4.9–5.1 percent pods (out of 10) and seed (out of 25) that when plated produced colonies of known pathogens, and foliar disease severity ratings based on a scale, where 0 = no disease, and 100 = dead plants.

			Pod	Seed		Foliar		
Variety	**MG**	**Tech**	**Phom.†**	**Phom. †**	**PSS†**	**TS†**	**CLB†**	**Yield§**
AGS GS49X19	4.9	Xtend	10	4	8	1.0 de‡	7.0 bc	74.6 a-i
Armor X49D67	4.9	Xtend	30	0	4	1.3 de	1.3 bc	62.3 b-i
Asgrow AG49X9	4.9	Xtend	20	0	8	2.3 cde	4.0 bc	83.6 a-h
Credenz CZ4918LL	4.9	LL	70	7	4	4.0 b-d	3.7 bc	66.8 a-i
Credenz CZ4938LL	4.9	LL	10	5	0	0.3 de	3.7 bc	60.3 b-i
Credenz CZ4979X	4.9	Xtend	40	0	16	1.3 de	2.3 bc	63.6 a-i
Delta Grow 4977LL/STS	4.9	LL/STS	30	0	4	6.7 abc	8.3 bc	73.2 a-i
Delta Grow 49E29	4.9	E3	20	0	4	0.0 e	6.7 bc	75.9 a-i
Delta Grow 49X15	4.9	Xtend	20	0	4	1.0 de	1.0 bc	76.8 a-i
Dyna-Gro S49EN79	4.9	Enlist	30	0	8	3.7 b-e	4.3 bc	61.2 b-i
Dyna-Gro S49XT39	4.9	Enlist	40	0	12	1.3 de	4.3 bc	82.9 a-h
Dyna-Gro S49XT70	4.9	Xtend	10	0	5	1.0 de	1.0 bc	93.2 a-g
Go Soy 49G16	4.9	RR1	50	0	8	0.7 de	1.7 bc	91.7 a-g
LGS4931RX	4.9	Xtend	10	0	13	2.7 cde	4.7 bc	84.2 a-h
Local LSX4901X	4.9	Xtend	0	0	0	1.0 de	1.0 bc	90.3 a-h
Mission A4950X	4.9	Xtend	40	0	4	0.7 de	2.7 bc	87.5 a-h
NK S49-F5X	4.9	Xtend	20	0	0	1.0 de	0.7 bc	80.2 a-i
Petrus Seed 4916GT	4.9	RR1	56	0	12	0.3 de	1.0 bc	72.6 a-i
Progeny P4999RX	4.9	Xtend	20	0	0	0.7 de	1.3 bc	81.7 a-h
REV 4927X	4.9	Xtend	30	3	7	0.7 de	0.7 bc	85.5 a-h
REV 4940X	4.9	Xtend	30	0	7	4.7 b-e	1.3 bc	89.5 a-h
USG 7496XTS	4.9	Xtend/STS	10	0	20	1.3 de	1.7 bc	88.9 a-h
AgriGold G5000RX	5.0	Xtend	0	0	17	0.7 de	1.3 bc	62.3 b-i
Go Soy 50G17	5.0	RR1	50	0	5	0.3 de	1.0 bc	69.3 a-i
Local LS5087X	5.0	Xtend	10	0	4	0.7 de	1.0 bc	69.5 a-i
Progeny P5016RXS	5.0	Xtend/STS	10	0	8	0.7 de	3.7 bc	53.4 b-i
Armor 51-D77	5.1	Xtend	30	0	4	1.0 de	1.7 bc	66.1 a-i
Credenz CZ5150LL	5.1	LL	0	0	8	1.0 de	4.0 bc	81.2 a-h
Eagle Seed ES5155RYX	5.1	Xtend	20	9	22	4.0 b-e	1.3 bc	73.3 a-i
Go Soy 512E18	5.1	E3	20	0	4	0.0 e	2.3 bc	87.1 a-h
Hefty H51E9	5.1	E3	30	0	18	0.0 e	2.3 bc	71.1 a-i
Progeny P5170RX	5.1	Xtend	30	0	4	1.3 de	1.3 bc	73.3 a-i
R15-1587	5.1	Conv.	50	0	0	0.0 e	1.3 bc	56.4 b-i
R16-2546C	5.1	Conv.	60	0	8	0.0 e	0.7 bc	59.1 b-i
R16-39	5.1	Conv.	10	0	0	0.0 e	1.0 bc	55.4 b-i

† Phom. = *Phomopsis* spp.; PSS = Purple seed stain (*Cercospora* spp.); TS = Target Spot (*Corynespora cassiicola*); CLB = Cercospora leaf blight (*Cercospora* spp.).

‡ Foliar disease severity ratings and yield columns followed by the same letter are not statistically significant at P = 0.10 as determined by Tukey's honestly significant difference test.

§ Yield (bu./ac) adjusted to 13%.

Table 7. Soybean maturity groups (MG) 5.2–5.6 percent pods (out of 10) and seed (out of 25) that when plated produced colonies of known pathogens, and foliar disease severity ratings based on a scale, where 0 = no disease, and 100 = dead plants.

			Pod	Seed		Foliar		
Variety	**MG**	**Tech**	**Phom.†**	**Phom.†**	**PSS†**	**TS†**	**CLB†**	**Yield§**
Armor 52-D71	5.2	Xtend	20	0	24	1.0 de‡	1.0 bc	75.1 a-i
Asgrow AG52X9	5.2	Xtend	10	0	0	1.3 de	1.0 bc	72.1 a-i
Credenz CZ5299X	5.2	Xtend	20	0	0	1.3 de	1.3 bc	78.0 a-i
Delta Grow 52E22	5.2	E3	0	0	24	0.0 e	1.0 bc	64.5 a-i
Delta Grow 52X05	5.2	Xtend/STS	10	0	3	1.0 de	2.3 bc	77.5 a-i
Dyna-Gro S52XS39	5.2	Xtend/STS	20	0	0	1.3 de	2.3 bc	83.9 a-h
Progeny P5211 E3	5.2	E3	20	0	7	0.0 e	2.3 bc	64.4 a-i
Progeny P5252RX	5.2	Xtend	0	3	3	4.3 b-e	1.3 bc	85.2 a-h
R16-2547	5.2	Conv.	0	0	0	0.0 e	2.0 bc	53.9 b-i
Asgrow AG53X0	5.3	Xtend	10	0	8	2.7 cde	1.3 bc	62.0 b-i
Local LS5386X	5.3	Xtend	10	0	11	1.3 de	5.7 bc	83.2 a-h
Progeny P5335RX	5.3	Xtend	30	0	0	1.0 de	1.0 bc	70.2 a-i
R13-818	5.3	Conv.	44	0	0	0.0 e	2.0 bc	56.7 b-i
Delta Grow 54X25	5.4	Xtend	30	0	4	2.7 cde	4.0 bc	80.4 a-i
R13-13997	5.4	Conv.	20	0	10	0.0 e	1.3 bc	79.0 a-i
R13-14635RR	5.4	RR1	10	0	8	0.7 de	2.7 bc	82.8 a-h
R14-1422	5.4	Conv.	20	5	0	0.0 e	1.7 bc	74.5 a-i
R16-1445	5.4	Conv	40	0	0	0.0 e	1.3 bc	85.2 a-h
R16-378	5.4	Conv.	30	0	4	0.0 e	2.0 bc	80.5 a-i
Armor 55-D57	5.5	Xtend	30	0	0	1.0 de	1.3 bc	54.1 b-i
Delta Grow 5585RR2	5.5	RR2	20	0	10	0.3 de	1.3 bc	75.7 a-i
Local LS5588X	5.5	Xtend	20	0	7	1.0 de	1.3 bc	56.3 b-i
Progeny P5554RX	5.5	Xtend	89	5	0	1.3 de	2.3 bc	73.8 a-i
Dyna-Gro S56XT99	5.6	Xtend	10	0	0	1.0 de	12.0 bc	61.6 b-i
Progeny P5688RX	5.6	Xtend	40	0	10	1.0 de	2.3 bc	84.4 a-h

† Phom. = *Phomopsis* spp.; PSS = Purple seed stain (*Cercospora* spp.); TS = Target Spot (*Corynespora cassiicola*); CLB = Cercospora leaf blight (*Cercospora* spp.).

‡ Foliar disease severity ratings and yield columns followed by the same letter are not statistically significant at *P* = 0.10 as determined by Tukey's honestly significant difference test.

§ Yield (bu./ac) adjusted to 13%.

Determining the Value of Fungicide Application on a Regional, Field Level, and Within-Field Scales

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Abstract

Fungicide strip trials were placed in Hamburg, Eudora, and Kelso, Ark. Foliar disease levels were determined across replicated fungicide treatment strips and disease distributions determined independently of fungicide treatments. Foliar diseases tended to be aggregated (clustered), which agrees with other findings and disagrees with the common thought that they occur randomly. Applied fungicide products did not increase yield above the untreated control likely due to a lack of disease pressure.

Introduction

Soybean [*Glycine max*, (L.) Merr.] is grown on approximately 3.3 million acres in Arkansas, generating an estimated $1.7 billion annually (Ross, 2017). Foliar diseases are widespread in the state's production area and cause economic losses each year.

Management recommendations for foliar diseases involve cultural practices, resistant varieties, and foliar fungicide applications if warranted, after scouting. Unfortunately, scouting is not an exhaustive process. Individually, crop consultants are responsible for more cropland than ever before, with management decisions made from field subsets often not representative of whole field disease severity. Many foliar fungicides are labeled for soybean in Arkansas, with new products introduced into the market annually. Determining whether to apply a fungicide or which product is most effective for a disease or combination of diseases, can be a complex process for consultants and farmers. Additionally, the annual generation of data for products across many different field environments to confirm their efficacy and generate actionable economic disease thresholds are required. This work aims to address these issues with two main objectives: to understand foliar disease distributions and determine product efficacy in on-farm trials.

Procedures

In 2019, fungicide strip trials were established on grower fields in Hamburg, Eudora, and Kelso, Ark. Treatments were replicated three times in a randomized complete block design. Applications were made at 10 gallons per acre (GPA) using a ground-driven sprayer. The width of each strip was determined based on the farmer's combine header width, and applications were made the entire length of each field. Disease incidence and severity ratings in the top 1/3 of the canopy were evaluated at R6 at 10 georeferenced points in each strip. Disease incidence ratings were based on a percentage scale where 0 = no disease and 100 = all plants in the rating area had disease. Disease severity ratings were based on a percentage scale where 0 = no disease and 100 = dead plants. Harvest data was provided from yield monitors located on the farmer's combine. Additional untreated strips were included and utilized to determine disease distribution. Fungicides used in all locations were: Priaxor® (4 fl oz/ac), Tilt® (6 fl oz/ac), Priaxor + Tilt, Trivapro® (20.7 fl oz/ac), Tilt (4 fl oz/ac) and Quilt® Xcel (21 fl oz/ac). All products were applied at the R3 growth stage. Applications were made on 18 June, 20 June, and 25 July at Hamburg, Eudora, Kelso, respectively. Disease ratings from points within strips were spatially analyzed in GeoDa software (Center for Spatial Data Science, University of Chicago) using a statistic called Moran's I to determine diseases' distribution: aggregated (clustered), uniform (evenly spread) or random.

Diseases were considered aggregated (or uniform) when P-values were equal to or less than 0.10. If the *P*-value from the Moran's I analysis was above 0.10, the disease distribution was estimated to be random. Disease ratings from all treatment strips were subjected to analysis of variance followed by means separation of fixed effects using Tukey's honestly significant difference test (HSD) at $P = 0.05$.

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Results and Discussion

At the Hamburg location, Target spot (TS), frogeye leaf spot (FLS), and Cercospora leaf blight (CLB) incidence and severity were assessed on 11 Sep and again on 23 Sep, at R6. Disease incidence was minimal on 11 Sept. Spatial analysis indicated incidence of FLS ($P < 0.04$), TS ($P < 0.01$), and FLS ($P < 0.01$) were aggregated while only severity of TS was aggregated ($P < 0.01$). Frogeye leaf spot incidence was significantly lower in the Trivapro strips than in other treatments. Incidence of CLB was significantly higher in the Trivapro strips than other treatments except for Priaxor + Tilt, but no differences were observed in severity. Yields in the test ranged from 48.3–50.3 bu./ac. None of the treatments had a significant impact on yield (Table 1).

At the Eudora location, no disease was present at the application. Foliar diseases were evaluated on 19 Aug. Target spot incidence and severity were determined at R6. Other diseases were not at detectable levels. Spatial analysis indicated TS incidence was uniform throughout the field, meaning that all plants rated had TS. Target spot severity trended toward aggregation (0.12).

Target spot incidence and TS severity had no significant differences from the untreated strips. The provided yield map was incomplete, and therefore yields are omitted (Table 2).

At Kelso, TS incidence and severity were determined 6 Sep. Other diseases such as FLS or CLB were not at detectable levels. The spatial analysis determined that TS incidence was aggregated ($P < 0.01$), and TS severity trended toward aggregation (0.14). Priaxor + Tilt significantly suppressed TS incidence above the untreated and all other treatments except Trivapro. No treatment provided a yield increase above the untreated control.

Practical Applications

Foliar disease distributions were mostly aggregated or trended that way, in agreement with other findings of foliar disease distributions (Waggoner and Rich, 1981) and disagreeing with common thought that diseases occur randomly. Mixed modes of action products had some efficacy but did not consistently increase yield above the untreated control, probably due to a lack of disease pressure. The aggregation of the foliar diseases found in these tests is important because it suggests that we could develop preferential scouting models and actionable tools that can increase scouting efficiency and allow us to better understand when to apply a fungicide. As we learn why diseases occur in specific areas, the creation and use of reliable tools should be possible.

Acknowledgments

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Table 1. Fungicide strip trial treatments, disease data, and yield at Hamburg, Arkansas, 2019.

Treatment rate/ac	FLS† INC	FLS† SEV	TS† INC	TS†SEV	CLB† INC	CLB† SEV	Yield§
							bu./ac
Tilt® 6 oz	60.6 ab‡	1.1	81.3	1.9	31.8 a	1.0	50.30
Priaxor® 4 oz + Tilt 6 oz	59.6 ab	1.2	84.0	2.2	40.6 ab	1.3	50.26
Trivapro® 20.7 oz	51.4 a	1.1	80.0	1.9	48.3 b	1.2	49.64
Quilt® Xcel 21 oz	65.3 b	1.4	81.3	2.4	28.3 a	1.0	49.11
Untreated	63.8 b	1.1	80.7	1.9	27.9 a	1.1	48.64
Priaxor 4 oz	58.3 ab	1.2	80.3	2.0	29.0 a	1.3	48.30
Pr(>F)	0.02	0.46	0.65	0.77	<0.0001	0.85	0.95

† Frogeye leaf spot (FLS), target spot (TS), and Cercospora leaf blight (CLB) disease incidence (INC) ratings were based on a percentage scale where 0 = no disease and 100 = all plants in the rating area with disease. Disease severity (SEV) ratings were based on a percentage scale where 0 = no disease and 100 = dead plants. Target spot severity was estimated as the average height target spot was found to the soil, expressed as a percentage.

‡ Columns followed by the same letter are not statistically significant at $P = 0.05$, as determined by Tukey's honestly significant difference test (HSD).

§ Yields adjusted to 13% moisture content for comparison. Harvest data was provided from yield monitors located on the combine.

Table 2. Fungicide strip trial treatments, disease data, and yield at Eudora, Ark., 2019.

Treatment rate/ac	TS INC†	TS SEV†
Tilt® 6 oz	100	7.9
Priaxor® 4 oz + Tilt 6 oz	100	8.1
Trivapro® 20.7 oz	100	7.5
Quilt® Xcel 21 oz	100	7.9
Untreated	100	7.9
Priaxor 4 oz	100	8.1
Pr(>F)	1	0.88

† Target spot (TS) disease incidence (INC) ratings were based on a percentage scale where 0 = no disease and 100 = all plants in the rating area with disease. Disease severity (SEV) ratings were based on a percentage scale where 0 = no disease and 100 = dead plants. Target spot severity was estimated as the average height target spot was found to the soil, expressed as a percentage.

Table 3. Fungicide strip trial treatments, disease data, and yield at Kelso, Ark., 2019.

Treatment rate/ac	TS INC†	TS SEV†	Yield §
			bu./ac
Tilt® 6 oz	32.2 b‡	4.2	52.1 a
Priaxor® 4 oz + Tilt 6 oz	21.0 a	3.7	52.4 a
Trivapro® 20.7 oz	26.8 ab	3.4	62.2 ab
Quilt® Xcel 21 oz	30.6 b	3.4	68.5 b
Untreated	30.3 b	3.7	59.3 ab
Priaxor 4 oz	33.2 b	4.0	55.3 a
Pr(>F)	0.043	0.675	0.049

† Target spot (TS) disease incidence (INC) ratings were based on a percentage scale where 0 = no disease and 100 = all plants in the rating area with disease. Disease severity (SEV) ratings were based on a percentage scale where 0 = no disease and 100 = dead plants. Target spot severity was estimated as the average height target spot was found to the soil, expressed as a percentage.

‡ Columns followed by the same letter are not statistically significant at $P = 0.05$ as determined by Tukey's honestly significant difference test (HSD).

§ Yields adjusted to 13% moisture content for comparison. Harvest data was provided from yield monitors located on the combine.

Effect of Termination Dates of Cereal Rye Cover Crop on Soybean Seedling Disease and Yield

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Abstract

Cereal rye (*Secale cereal*) was planted with a drill after harvest soybean on 31 Oct. 2018 at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station, at Marianna, Ark. There were four termination dates: termination in January, February, March, and at planting, 15 May. Cover crop biomass was determined at planting. The test was planted with the soybean cultivar Credenz 4748LL treated with either ApronMaxx® + Vibrance®, ApronMaxx + Vibrance + Cruiser®, ApronMaxx + Vibrance + Cruiser + Avicta®, Allegiance® alone, Sedaxane® alone, or untreated. The soil was sampled at planting and assayed for soil microbes, including nematodes. There were no significant effects on soil microbes or nematodes due to cover crop or seed treatment; however, soil sampled at harvest for nematodes had significantly greater soybean cyst nematode egg densities in the cover crop terminated at planting and with seed treated with the nematicide Avicta. This is the first year of the cover crop termination study. We expect to see greater differences between cover crop treatments and seed treatments in the future with the cumulative effects of these cover crop treatments on soil health.

Introduction

Growers are turning to winter cover crops to control erosion, nutrient runoff, and to improve soil health by changing the physical, chemical, and biological characteristics of the soil (Martinez-Garcia et al. 2018; Schmidt et al., 2018). Some cover crops have also been reported to reduce soilborne diseases and plant-parasitic nematode (Bates and Rothrock, 2005; Cochran and Rothrock, 2008; Eastburn, 2014; Lodha et al., 2003; Wen et al., 2017). Cereal rye (*Secale cereal*) is one of the most reliable and effective cover crops. It produces high levels of biomass, improves soil health, reduces weed pressure, and can suppress plant diseases.

In soybean, cereal rye cover crop reduced soil densities of soybean cyst nematode (SCN) and suppressed seedling diseases caused by *Rhizoctonia solani* (Wen et al., 2017). A challenge in managing cereal rye as a cover crop is deciding when to terminate it.

Late termination of cereal rye produces the greatest amount of biomass, leading to the greatest increase in soil organic matter and the greatest weed suppression (Balkcom et al., 2016). However, late termination under dry-land conditions may reduce soil moisture leading to reduced stands. In corn, late termination of cereal rye increased seedling diseases on corn, including several caused by *Pythium* spp. (Acharya et al., 2017; Bakker et al., 2016). Many *Pythium* spp. are important pathogens of soybean. In practice, growers may terminate cover crops anywhere from two or three months before planting up until planting. The objective of this research was to determine the effect of cereal rye termination dates and seed treatments on soybean disease and yield.

Materials and Methods

Cereal rye was planted after harvest soybean on 31 Oct. 2018 at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station, at Marianna, Ark. The cereal rye was planted with a drill over the entire test. There were four termination dates: January, February, March, or at planting (15 May). A mixture of Grammoxone® and glyphosate was used to terminate the cereal rye. Cover crop biomass was determined at soybean planting. The cover crop treatments were in 24 by 200 ft plots in four replications. The soybean cultivar Credenz 4748LL was planted in 38 in. rows at 80,000 seed/ac in plots that were 20-ft long and 4 rows wide. A low seeding rate was used to amplify the effects on yield of reductions in plant stands and vigor due to seedling disease. In each cover crop plot, there were six soybean seed treatments: ApronMaxx® + Vibrance®, ApronMaxx + Vibrance + Cruiser®, ApronMaxx + Vibrance + Cruiser + Avicta®, Allegiance® alone, Sedaxane® alone, and an untreated control. These seed treatments controlled either fungi, fungi and insects, fungi, insects, and nematodes, *Pythium* spp., *Rhizoctonia solani*, or no added control, respectively. The soybean plots were planted no-till on 15 May.

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Stand counts were made at 2 and 4 weeks after planting from the center two rows of each seed treatment plot. Soil samples were taken from each cover crop termination date at planting, and the densities of fungi, oomycetes, bacteria, and nematodes were determined. Additional soil samples for nematode analysis were taken from the control and the ApronMaxx + Vibrance+ Cruiser + Avicta (included nematode control agent Avicta) plots on 28 June and 18 Sept. Plots were harvested on 28 Sept.

Results and Discussion

There were significant differences in cereal rye biomass between cover crop termination dates (Fig. 1). Biomass increased as the termination was delayed, with the greatest biomass occurring at the terminated-at-planting treatment, followed by the March termination, with the January and February terminations having the least biomass.

With stand counts at four weeks, there was a significant effect with cover crop termination date, but not seed treatment (Fig. 2). Stands were high for most treatments, with 85% of planted seed producing viable seedlings. However, significantly lower stand counts occurred in treatments where the cover crop was terminated at planting. This was probably due to poor seed/soil contact because the presser feet could not completely close the planting furrow around the seed when planting into green cereal rye. Poor soil closure may have been due to drier soil since the cereal rye was still transpiring. In the other treatments, the cereal rye had been terminated more than a month before and so was not transpiring. Late cover crop termination has been reported to reduce stands under dry conditions (Balkcum et al., 2016). Lack of effect of any of the seed treatments on stand suggests that conditions did not favor seedling disease this year due to their need for high soil moisture.

There were no cover crop termination date effects on soil densities of fungi (14,388 cfu/ac), bacteria (96,109 cfu/g), oomycetes (503 cfu/g), or nematodes (soybean cyst eggs (498 eggs/20 cc soil) at planting. Also, *Rhizoctonia* populations were determined by baiting from soil using toothpicks and isolated in semi-selective media. Fifty-two isolates of *Rhizoctonia* were recovered from soil; where 42 isolates were binucleate *Rhizoctonia*, the remaining isolates were *R. solani* AG4 (2 isolates), and AG7 (1 isolate). Soil samples were sieved, and subsamples were taken for additional evaluation of microbial populations. In the coming years, the cumulative effects of different levels of biomass from the cereal rye should start affecting the soil microbial communities.

There were no cover crop termination date or seed treatment effects on nematode densities in June with SCN densities averaging 46 J2/200 cc soil and 123 eggs/200 cc soil. However, at harvest, there were significantly more SCN eggs in the plots terminated in May than in plots terminated in March or February, suggesting that dead cereal rye roots may be toxic to SCN but not live roots (Fig. 3). The decomposition of dead cereal rye roots may have changed the soil microbial community in ways that were more toxic to nematodes than changes with living cereal rye roots. It has been shown that cereal rye residue accumulates benzoxazinoids, which becomes toxic to nematodes when rye is incorporated into the soil (Timper 2017); however the release of this compound is greater in residue than living tissue, despite that living tissue has high levels of benzoxazinoids (Schulz et al., 2013). Seed treated with the nematicide Avicta resulted in significantly more SCN eggs at harvest than the untreated seed (285 vs. 97 eggs/200 cc soil, respectively). Nematode numbers were often higher at the end of the season with soil-applied nematicides than within the untreated plots because the nematicide resulted in healthier roots that could sustain a higher nematode population at the end of the season. The same may have happened here with the seed treated with Avicta. There were no significant yield effects from either the cover crop or the seed treatments. Yields averaged 55.9 bu./ac.

Soil from each cover crop plot was taken to the greenhouse and planted with from each seed treatment. The soil was kept moist, and stands were counted after two weeks. All stands were high, most 90% to 100%. There were no significant effects of either cover crop or seed treatment.

This is the first year of a long-term rotation study comparing the termination dates of a cereal rye cover crop. The differences in the accumulation of biomass due to the termination dates should begin to change to soil microbial communities with subsequent years. These changes should affect soybean disease development and yields.

Practical Applications

This research will determine the importance of seed treatments for soybean planted into a cereal rye cover crop terminated at different times. It will also determine if cover crops alone or in combination with a seed treatment will be effective in controlling seedling diseases and soybean cyst nematode. We will be able to track changes in soil health over several years of no-till and cover crop use that is associated with sustainable yields.

Acknowledgments

This research was funded by the Arkansas Soybean Promotion Board. We want to thank Station Director Claude Kennedy and Farm Manager Clayton Treat for managing our plots. This research was supported in part by the United States Department of Agriculture. Support was also provided by the University of Arkansas System Division of Agriculture.

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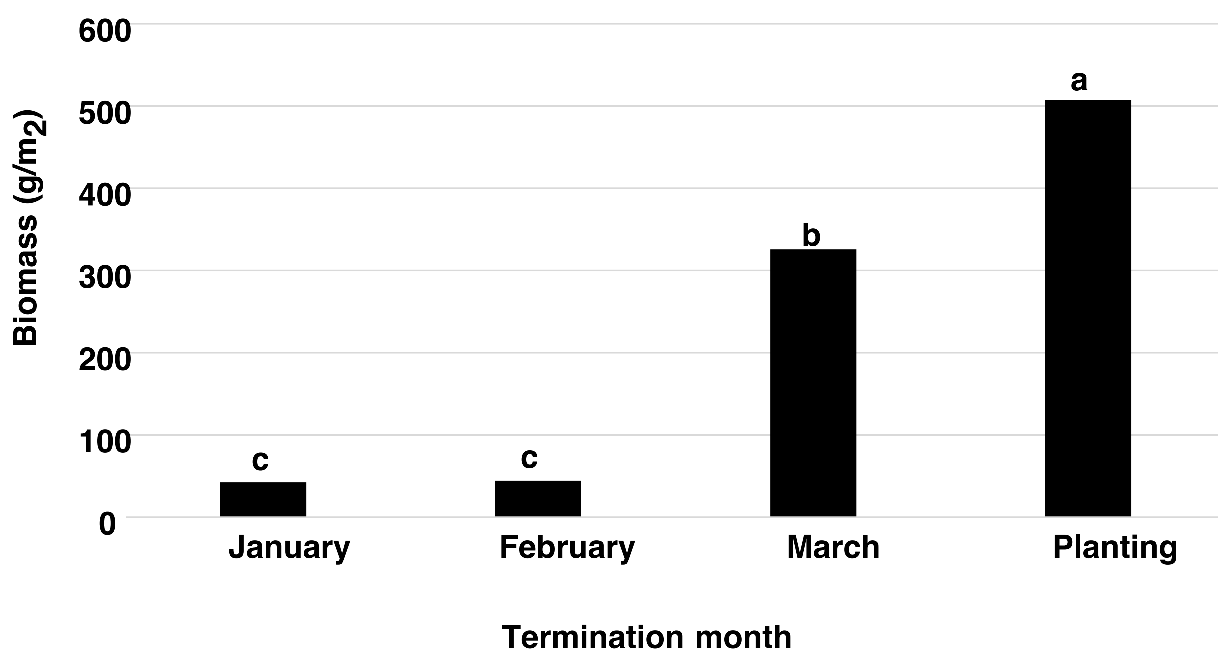

Fig. 1. Biomass (g/m²) at planting (15 May) of cereal rye (*Secale cereale)* terminated in January, February, March, and at planting. Bars with the same letter are not statistically significant (P < 0.05).

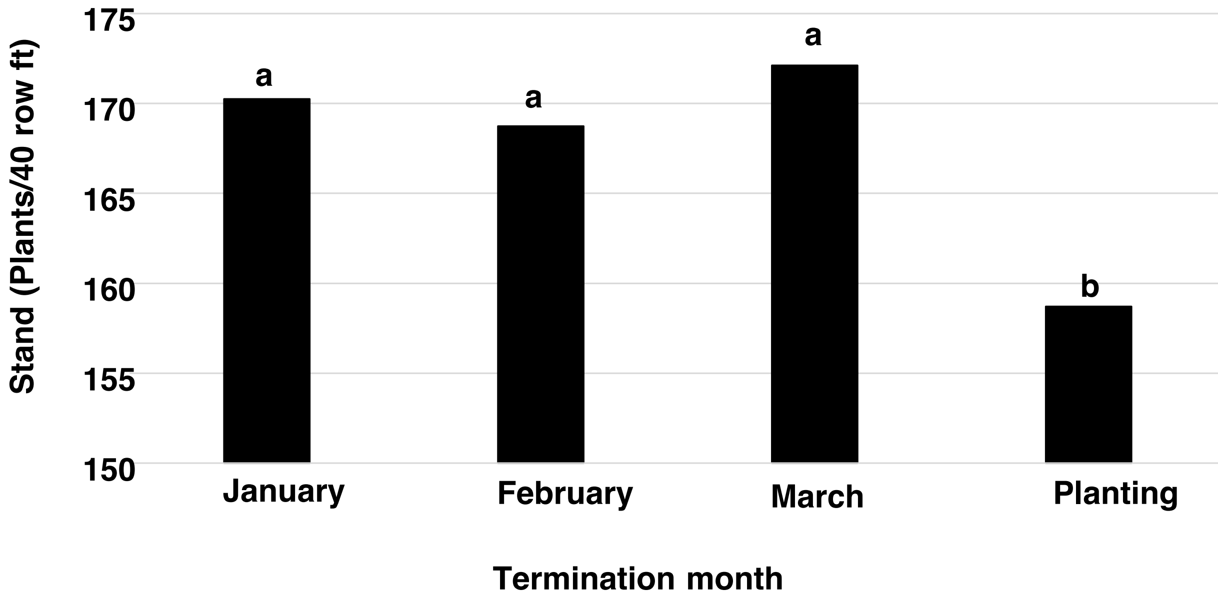

Fig. 2. Four-week soybean stand planted on May 15 into cover crops terminated at different times. Bars with the same letter are not statistically significant (P < 0.05).

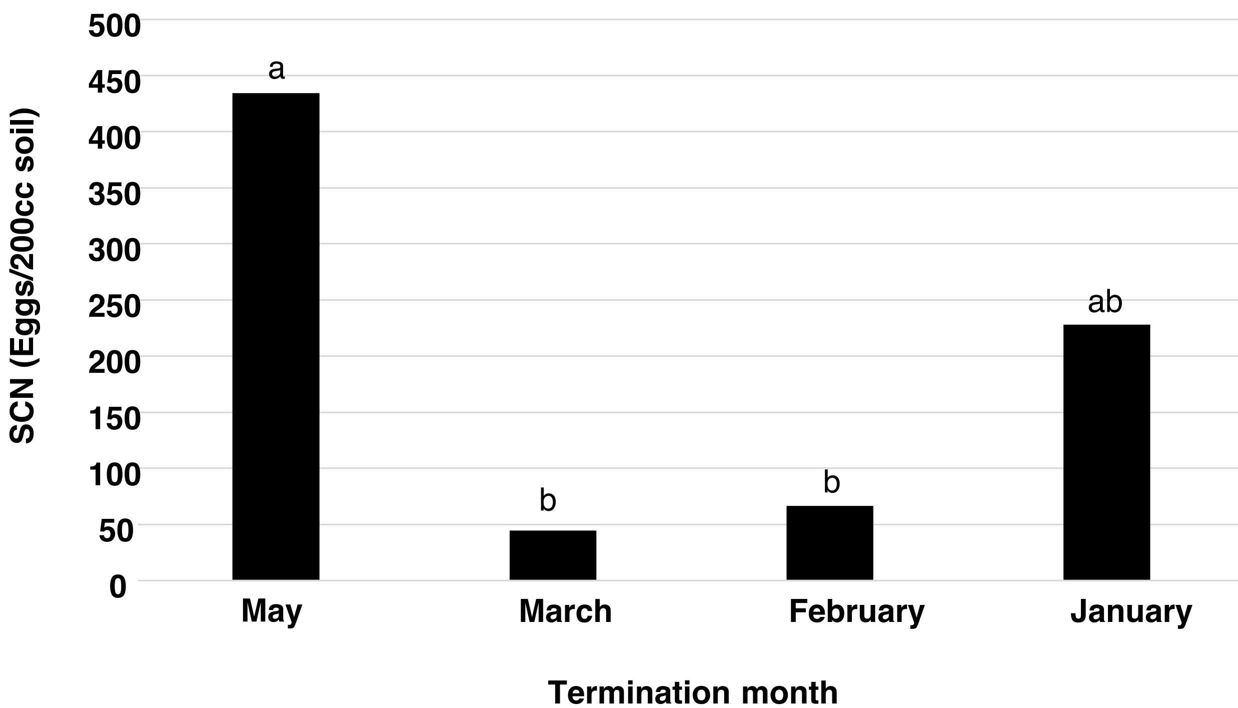

Fig. 3. Soybean cyst nematode eggs at harvest in cereal rye *(Secale cereale)* cover crops terminated in different months. Bars with the same letter are not statistically significant (P < 0.05).

Cost of Control for Major Insect Pests in Soybean in Arkansas, 2015-2019

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Abstract

The impacts of corn earworm, stink bugs, and soybean looper on soybean were recorded from 2015 through 2019. These estimates show that of the three, corn earworm was the costliest to control, averaging over $13.00 per acre, and reduced yield more than any other insect pests during this period. In 2017 stink bugs ($113 million) had a larger impact on soybean growers than corn earworm ($76 million). This was primarily due to redbanded stink bug, an occasional pest of tropical/subtropical regions, which were observed in great numbers due to a mild winter. Soybean looper caused less yield loss and required fewer applications per acre than corn earworm or stink bugs during these 5 years, however, their average cost of control was higher than either of the other two pests.

Introduction

Annual estimates of the impact insect pests have on soybean have been documented in Arkansas since 2009 (Musser, 2009). These estimates have been used to document yearly changes in insect pest pressure and associated costs of control. Based on this work, corn earworm, *Heliocoverpa zea* (Boddie), the stink bug complex, Hemiptera: Pentatomidae, and soybean looper, *Chrysodeixis includes* (Walker), have been observed to be the most yield-limiting and costly insect pests of soybean in Arkansas. The green stink bug, *Acrosternum hilare* (Say), and the brown stink bug *Euschistus servus* (Say) are the two most common species of stink bug observed feeding on soybean in Arkansas. Following a mild winter, the redbanded stink bug, *Piezodorus guildinii* (Westwood), migrates into Arkansas and can cause major yield loss as well as increase insect control costs. The objective of this report is to provide a record of the impact these insect pests have had on soybean producers in the past five years (2015–2019).

Procedures

The impact of soybean insect pests on soybean crop production was observed from 2015 through 2019 (Musser et al., 2015–2019). Estimates were made for acres infested, acres treated, applications per acre, cost of one application, the percent total loss due to a given pest, and the total losses plus cost to control for corn earworm, the stink bug complex, and soybean looper. Observations on multiple other insect pests were also made; however corn earworm, stink bugs, and soybean looper were the most important insect pests. Data were combined to observe yearly trends for these insect pests and to estimate how these changes have impacted soybean producers over time. Estimates were made through informal communication, including surveys with extension personnel, soybean producers, and consultants.

Results and Discussion

Acres Infested and Treated. Corn earworms were present in over 70% of the total soybean acres in Arkansas from 2015 to 2019, with an average of 81% of acres infested. During the same time, approximately 36% of soybean acres were treated for corn earworm, with a peak being observed in 2018 (46%). A majority of the fields requiring treatment were fields planted from late-May through July. The stink bug complex infested 100% of soybean acres during the past five years. Over this period, an average of 50% of the soybean acres was treated for stink bugs. During 2017 a large spike in acres treated (70%) for stink bugs was observed. This was due to redbanded stink bugs being the dominant stink bug present (Table 1). Soybean looper infested the fewest amount of acres during this time compared to corn earworm and the stink bug complex, with an average of just over 20% of the acres be-

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ing infested. Acres treated for soybean looper increased from less than 10% in 2015 to almost 30% in 2017, with an average of 20% over the entire 5-year period. (Figs. 1 and 2).

Applications Made and Cost of Applications. The number of insecticide applications made for corn earworm stink bugs and soybean looper has been relatively stable over the past five years. Applications for corn earworm ranged from 1.1–1.25 applications per acre with an average of 1.2 applications per acre. The cost of these applications averaged $13.20 during this time, with a peak cost of $17.50 per acre (2017). Soybean loopers averaged only 1 application per year during this time. The cost of an application for control of soybean looper has increased from $10.50 in 2016 to $17.50 from 2017-2019. This increase in price can be attributed to changes in the insecticides used to control soybean looper due to resistance issues. Stink bugs applications have ranged from 1–1.75 applications per acre over the past five years, with an average of 1.2 applications per acre. The peak of 1.75 applications per acre occurred during 2017 when redbanded stink bugs were the predominant species in the southern one-half of the state. The cost to control stink bugs has varied over the past five years, averaging $7.00 and $5.00 during 2015 and 2016, respectively. These years were dominated by green stink bugs, which can be controlled rather easily with a pyrethroid compared to brown or redbanded stink bugs. The price of control increased during 2017 to $14.00 per acre. This is due to the increase in redbanded stink bugs present, which are more difficult to control, usually requiring a tank mix of multiple chemistries to optimize control (Figs. 3 and 4).

Cost Plus Losses for Major Insect Pests. Corn earworm has caused more yield loss and costs more to control for soybean growers than the stink bug complex or soybean looper from 2015–2019. On average, corn earworm has accounted for over 35% of the total losses plus costs for soybean insect pests in Arkansas during this period, with an average yearly loss of $65 million. Stink bugs have averaged 24% of the total losses plus costs during this period. Stink bugs surpassed corn earworm in this category only during 2017, where they accounted for almost 40%, or $113 million, of the total losses plus costs. This was primarily due to the presence of redbanded stink bug that year. Soybean looper has averaged around 10% of the total losses plus costs from 2015 through 2019, costing growers a yearly average of almost $17 million (Figs. 5 and 6).

Practical Applications

Many insect pests can cause yield loss in soybean, but the corn earworm is by far the most damaging pest observed in soybean in Arkansas. Every year it costs growers more in yield loss and costs to control than all other pests. Stink bugs are the second most damaging pest observed in soybean in Arkansas. Typically they do not cause as much yield loss as corn earworm and are cheaper to control. On years where redbanded stink bugs are the dominant species of stink bug, the yield loss and costs to control these pests increased tremendously. Soybean looper can be extremely damaging for soybean producers. While this data shows they cause less impact on yield due to typically only infesting late-planted soybean, they are more expensive to control compared to stink bugs and corn earworm. Growers should keep these pests in mind when making their soybean crop budgets. This data also indicates the importance of planting soybeans as early as feasible. Many of these problems can be avoided with early planting.

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Table 1. Stink bug composition for Arkansas soybean from 2015 through 2019.

	% of total composition					
Stink Bug Species	**2015**	**2016**	**2017**	**2018**	**2019**	**5-Year Average**
Brown Stink Bug	25	40	25	43	25	32
Green Stink Bug	70	44	25	50	40	46
Redbanded Stink Bug	0	10	35	0	2	9
Redshouldered Stink Bug	2	1	5	7	8	5
Southern Green Stink Bug	3	5	10	0	25	8

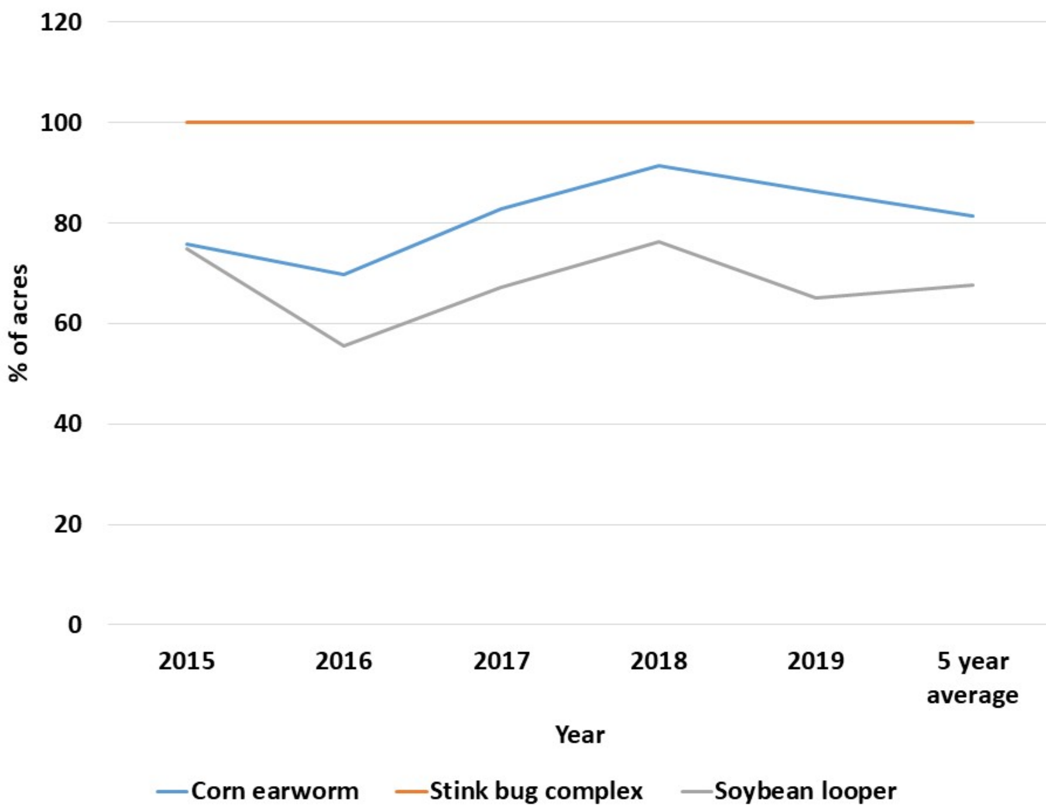

Fig. 1. Acres infested by major insect pests on soybean in Arkansas from 2015 through 2019.

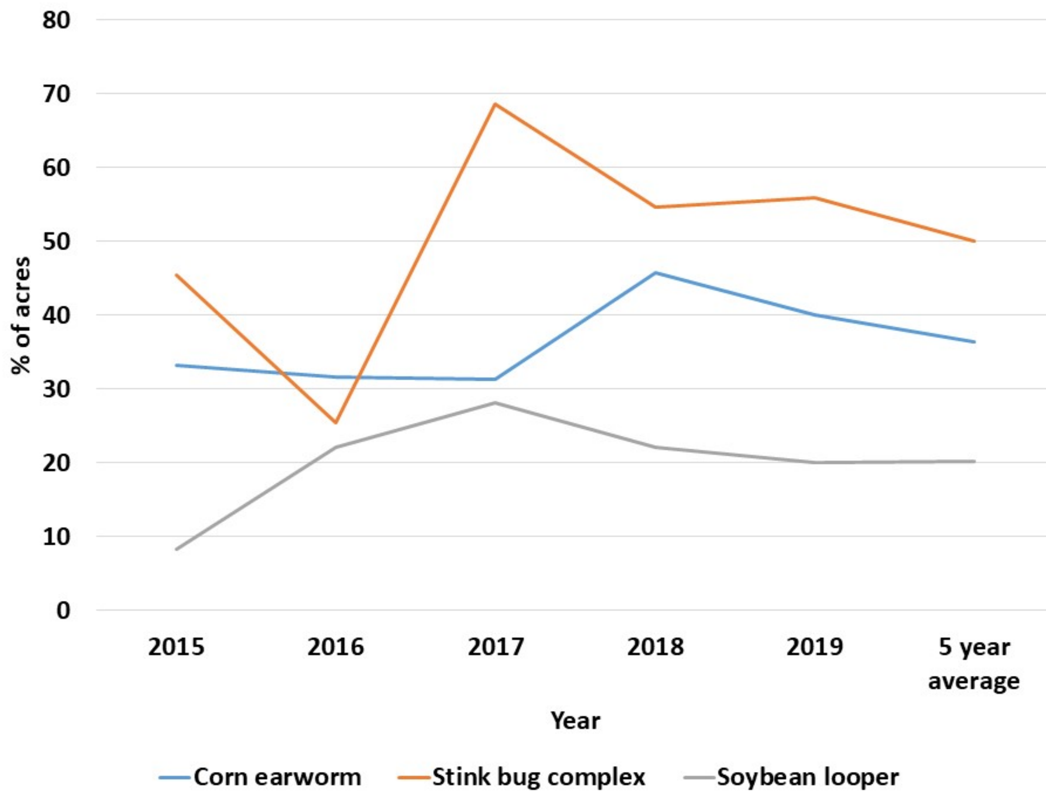

Fig. 2. Acres treated for major insect pests on soybean in Arkansas from 2015 through 2019.

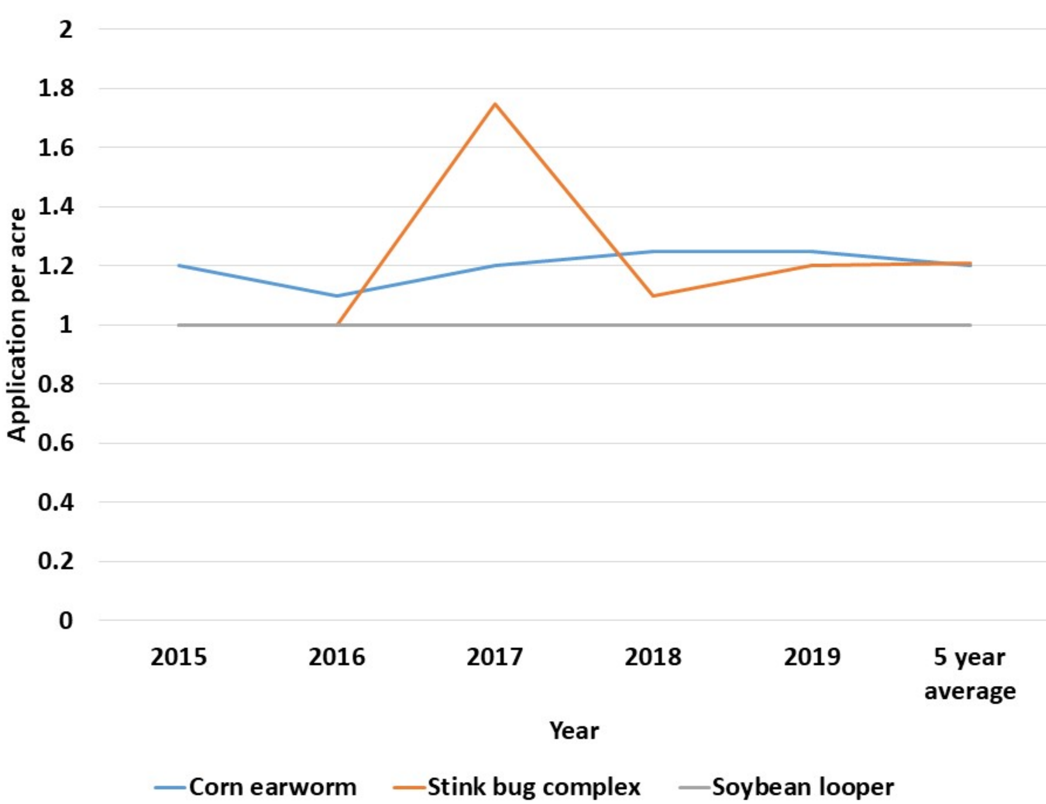

Fig. 3. Applications per acre for control of major insect pests on soybean in Arkansas from 2015 through 2019.

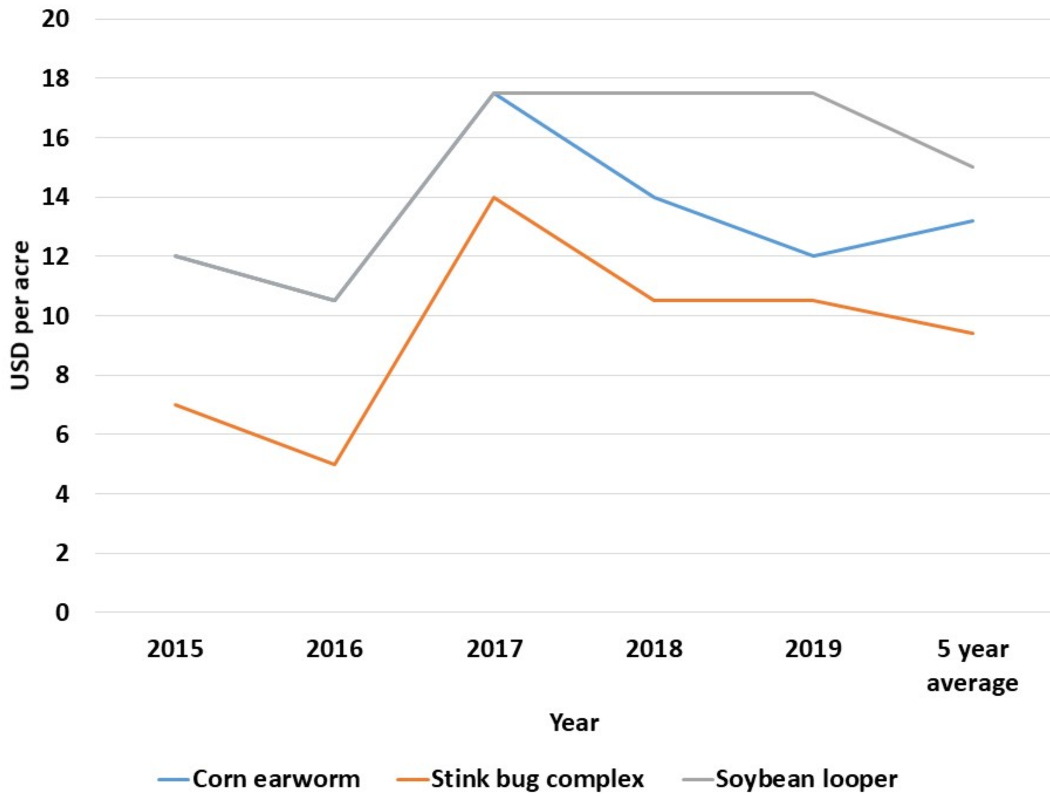

Fig. 4. Cost of one application for control of major insect pests on soybean in Arkansas from 2015 through 2019.

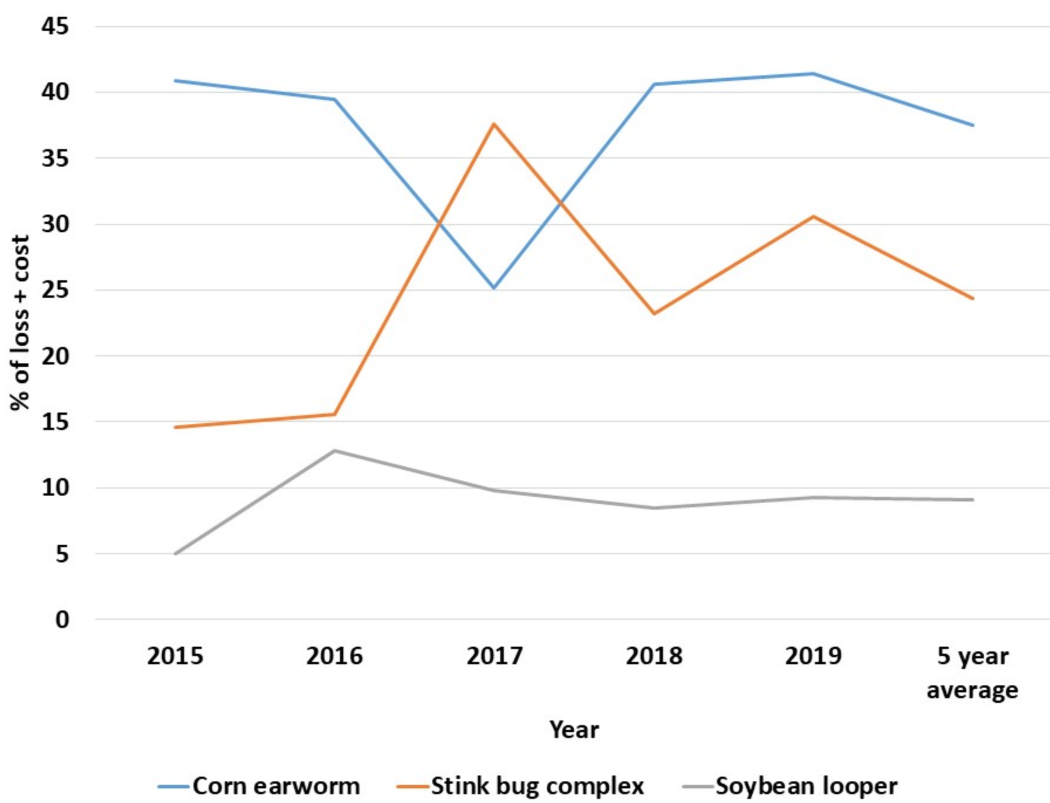

Fig. 5. Percent of total loss + cost of control for major insect pests on soybean in Arkansas from 2015 through 2019.

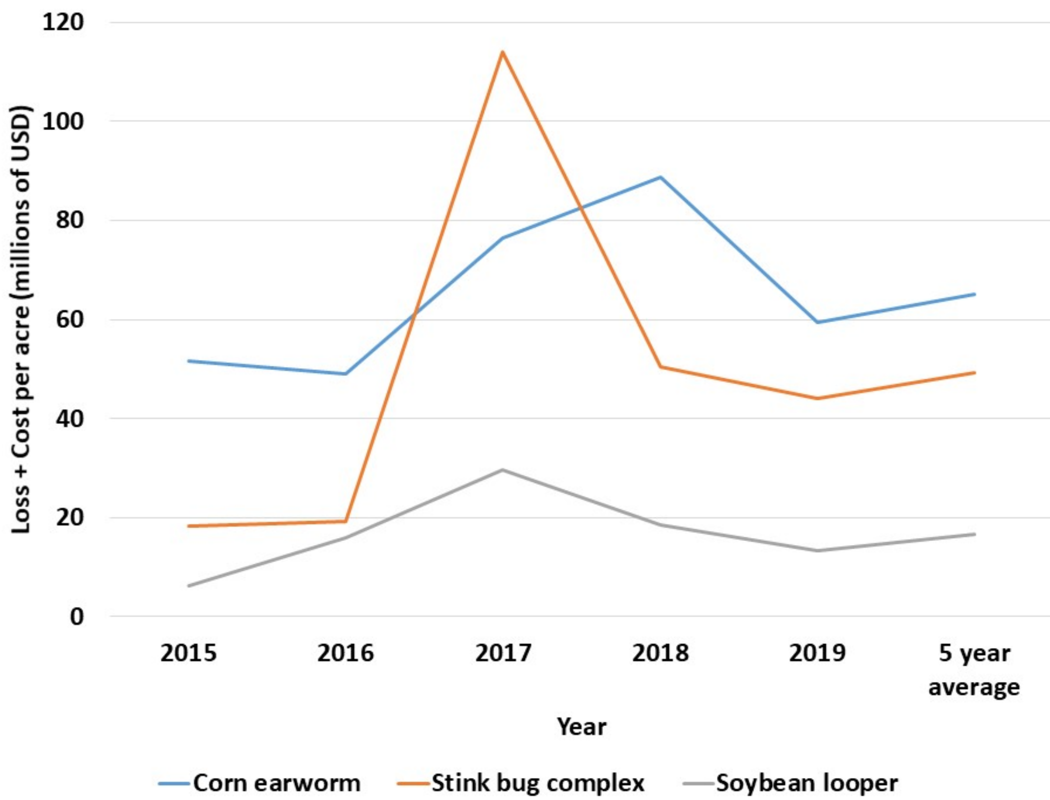

Fig. 6. Per acre loss + cost estimates for major insect pests on soybean in Arkansas from 2015 through 2019.

Efficacy of Selected Insecticides for Control of Soybean Looper, *Chrysodeixis includens*, in Soybean

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Abstract

Studies were conducted in 2019 to evaluate selected insecticides for control of soybean looper (SBL) in soybean. In the first trial, all insecticides lowered SBL numbers compared to the untreated control (UTC) 4 and 7 days after application (DAA), but products containing either methoxyfenozide or chlorantraniliprole tended to have better control of SBL. Similar results were observed in the second study, although Warrior® II did not reduce the SBL number compared to the UTC at 7 DAA. Generic methoxyfenozide products provided the same level of control as did Intrepid® 2F and Intrepid Edge® in the second study.

Introduction

Soybean looper (SBL), *Chyrsodeixis includens* Walker, can be a major pest of soybean in Arkansas, costing growers over 29 million dollars in 2017 (Musser et al., 2018) and over $18 million in 2018 (Musser et al., 2019). This pest feeds on soybean leaves, causing defoliation, ultimately resulting in yield loss. Soybean looper is a migratory pest which travels northward into Arkansas yearly from the far southern U.S. and Caribbean Islands and is typically only a pest of late-planted soybean (Carner et al., 1974). As the larvae develop, they eat irregular areas of leaves, leaving the larger leaf veins. Loopers are voracious feeders, particularly the large larvae (fourth-sixth instar), which consume 90% of the total food required by the developing larvae. Soybean loopers have been observed to occasionally feed on pods. Generally, loopers do not reach damaging levels in Arkansas due to the natural enemy complex of beneficial insects and pathogens. However, when they do occur, it is usually late in the season and typically in areas where cotton is also grown. Cotton nectar provides a carbohydrate source, which can greatly increase the egg production of the female moth. Soybean Looper has documented resistance to multiple insecticide modes of action (Leonard et al., 1990; Mascarenhas and Boethel, 1997); therefore it is important for efficacy testing of currently labeled products to be conducted yearly.

Procedures

Two studies were conducted at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station, at Marianna, Arkansas, to evaluate the efficacy of selected insecticides to control SBL. The field was planted with Progeny 5110RY variety soybean on May 16th. The plot size was 4 rows by 50-ft long planted on 30 in. rows, arranged in a randomized complete block design with 4 replications. Insecticides were applied on 20 Aug. at the R5.5 growth stage with a Mud-Master sprayer equipped with a multi-boom delivering 10 GPA at 40 psi through 80-02 dual flat fan nozzles with 19.5-in. spacing. (Table 1 and 2) Plots were sampled with a standard drop cloth, and two samples were taken per plot for a total of 10-row feet at 3 days after application (DAA) for trials 1 and 3 and 7 DAA for trial 2. In Soybean Looper Efficacy Trial 2, defoliation was estimated in each plot at both 3 and 7 DAA.

Results and Discussion

Soybean Looper Efficacy Trial 1. At 3 DAA, the untreated check (UTC) was averaging over 100 SBL per 10-row ft All insecticide treatments lowered SBL numbers below the UTC except Silencer®. Denim® at both rates and Intrepid Edge had fewer SBL than the Vexer® + Experimental (Fig. 1). At 7 DAA, the population had cycled out.

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Soybean Looper Trial 2. At 3 DAA, the UTC was averaging over 120 SBL per 10-row ft All treatments reduced SBL numbers compared to the UTC with Orthene®, leaving more loopers than all other treatments. Intrepid Edge had fewer SBL than Orthene and Intrepid at 4 oz/ac (Fig. 2). By 7 DAA, the UTC was averaging over 50 loopers/10 row ft. Orthene had a higher count than all other treatments, with no difference between all other treatments (Fig. 3). All treatments reduced the level of defoliation compared to the UTC; however, no differences were observed among treatments (Fig. 4). At 7 DAA, Intrepid, Prevathon, and Intrepid Edge all reduced the level of defoliation compared to the UTC and Orthene (Fig. 5).

Practical Applications

Soybean looper is a yearly pest of late-planted soybean and can cause significant yield loss. With the current cost of soybean production and low grain prices, growers need less expensive options for controlling insect pests in soybean. Currently, SBL has confirmed resistance to multiple classes of insecticides. Products such as Prevathon® and Besiege® still provide some control of these pests. Intrepid and Intrepid Edge have been the standard in SBL control of the past few years. Currently, there are multiple generic methoxyfenozide (Intrepid 2F) products on the market; and based on these studies, it appears that soybean producers could get adequate control of SBL with high rates of these generics and potentially save money.

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Table 1. Soybean Looper Efficacy Trial 1 treatment list.

Treatment	Active ingredient	Rate per acre
Silencer®	lambda-cyhalothrin	3.66 oz
Vexer® + Experimental	methoxyfenozide + experimental	4 oz + 4 oz
Vexer	methoxyfenozide	4 oz
Besiege®	chlorantraniliprole + lambda cyhalothrin	10 oz
Prevathon®	chlorantraniliprole	19 oz
Denim®	emamectin benzoate	8 oz; 12 oz
Intrepid Edge®	spinetoram + methoxyfenozide	5 oz

Table 2. Soybean Looper Efficacy Trial 2 treatment list.

Treatment	Active ingredient	Rate per acre
Intrepid®	methoxyfenozide	4 oz
Intrepid Edge®	spinetoram + methoxyfenozide	5 oz
Prevathon®	chlorantraniliprole	14 oz
Orthene®	acephate	1 lb

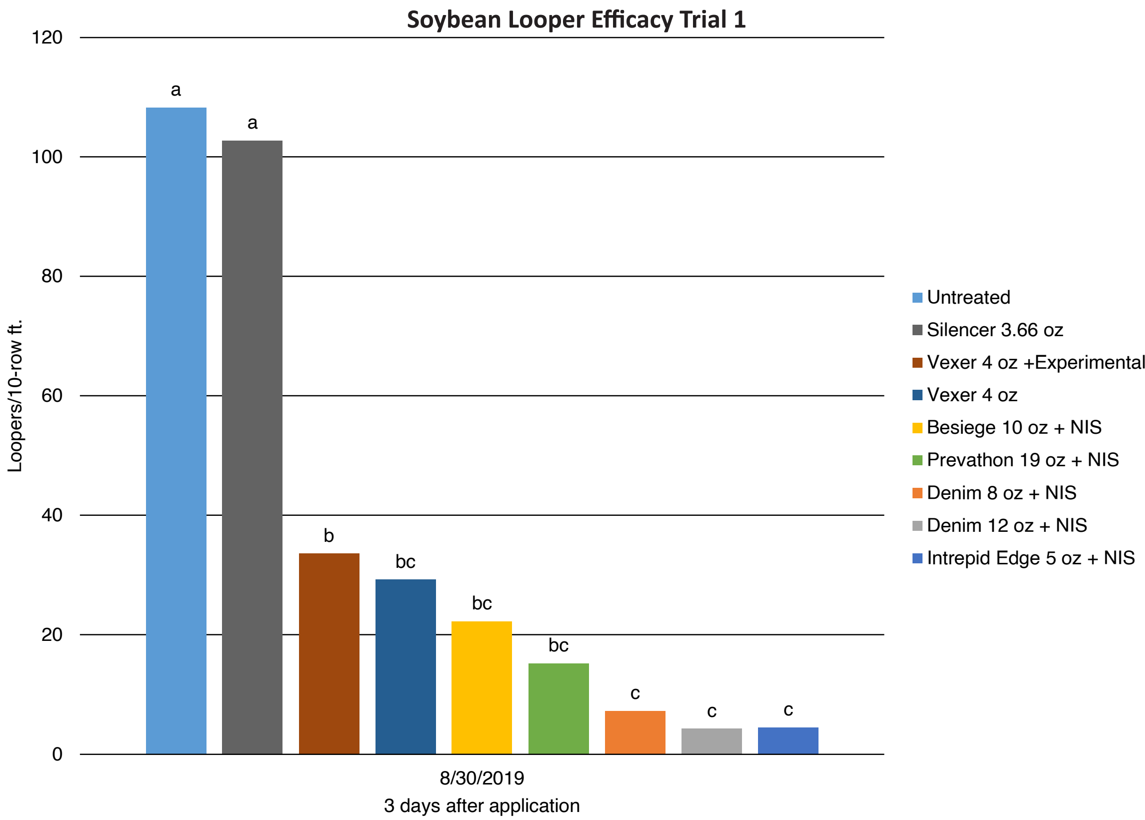

Fig. 1. A comparison among generic methoxyfenozide and current standard for control of soybean looper in Arkansas in 2019, 3 days after application.

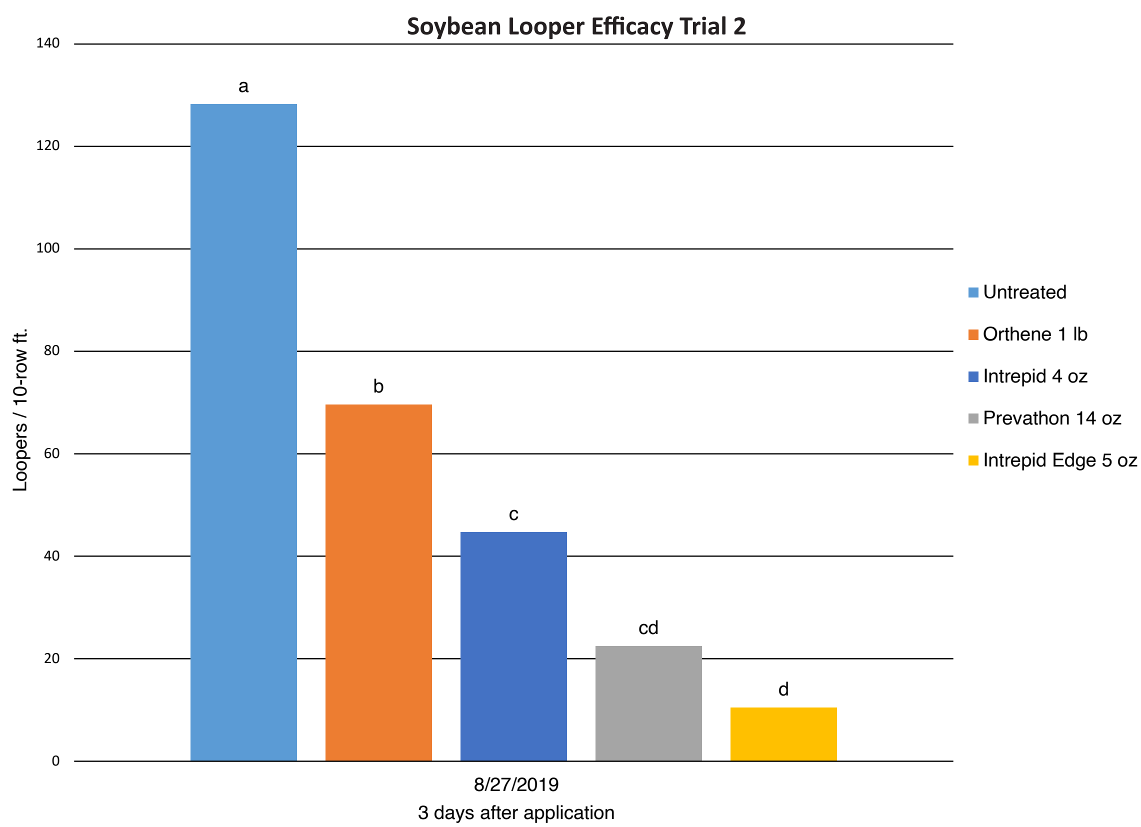

Fig. 2. Results comparing selected insecticides for control of soybean looper in Arkansas in 2019, larval counts 3 days after application.

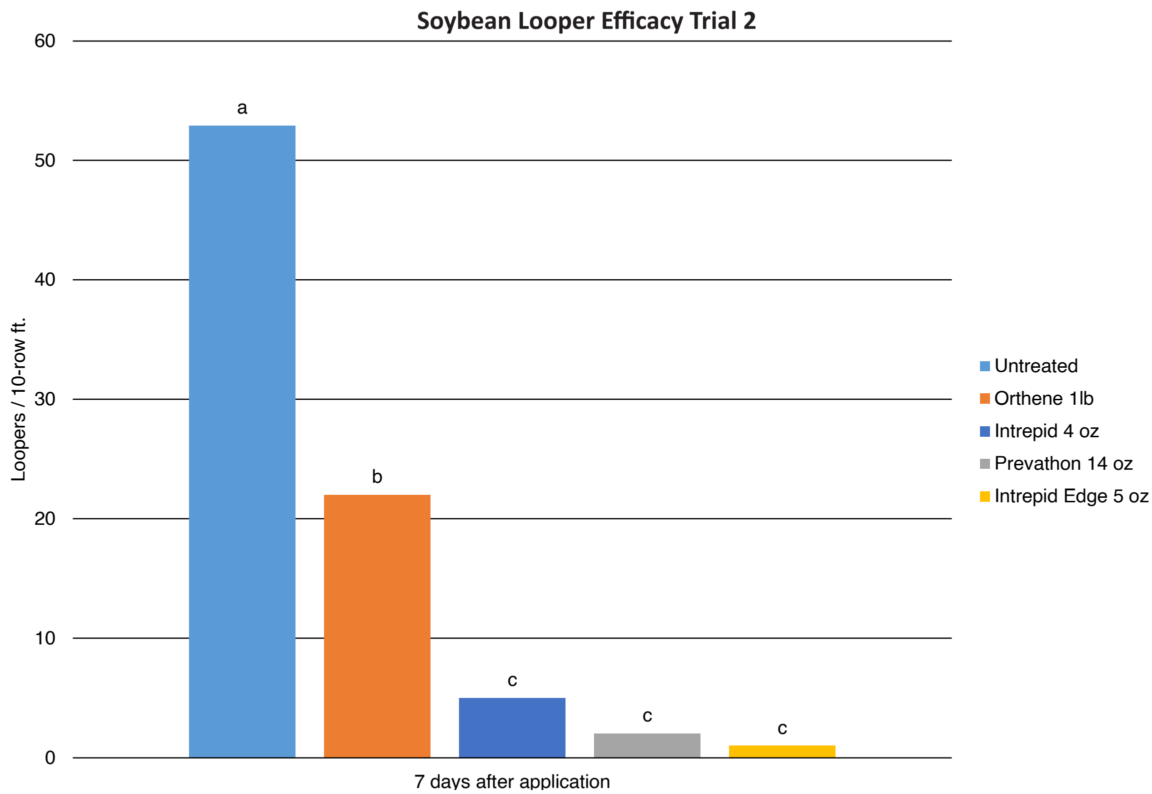

Fig. 3. Results comparing selected insecticides for control of soybean looper in Arkansas in 2019, larval counts 7 days after application.

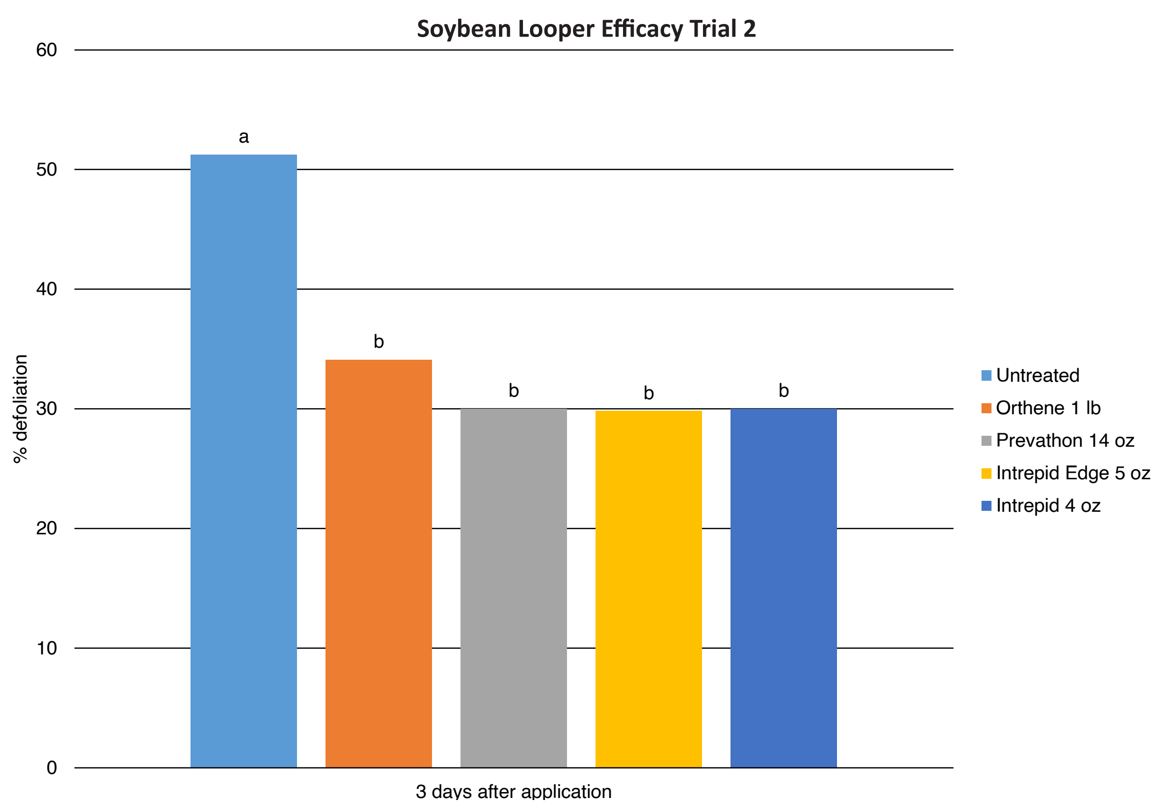

Fig. 4. Results comparing selected insecticides for control of soybean looper in Arkansas in 2019, defoliation ratings 3 days after application.

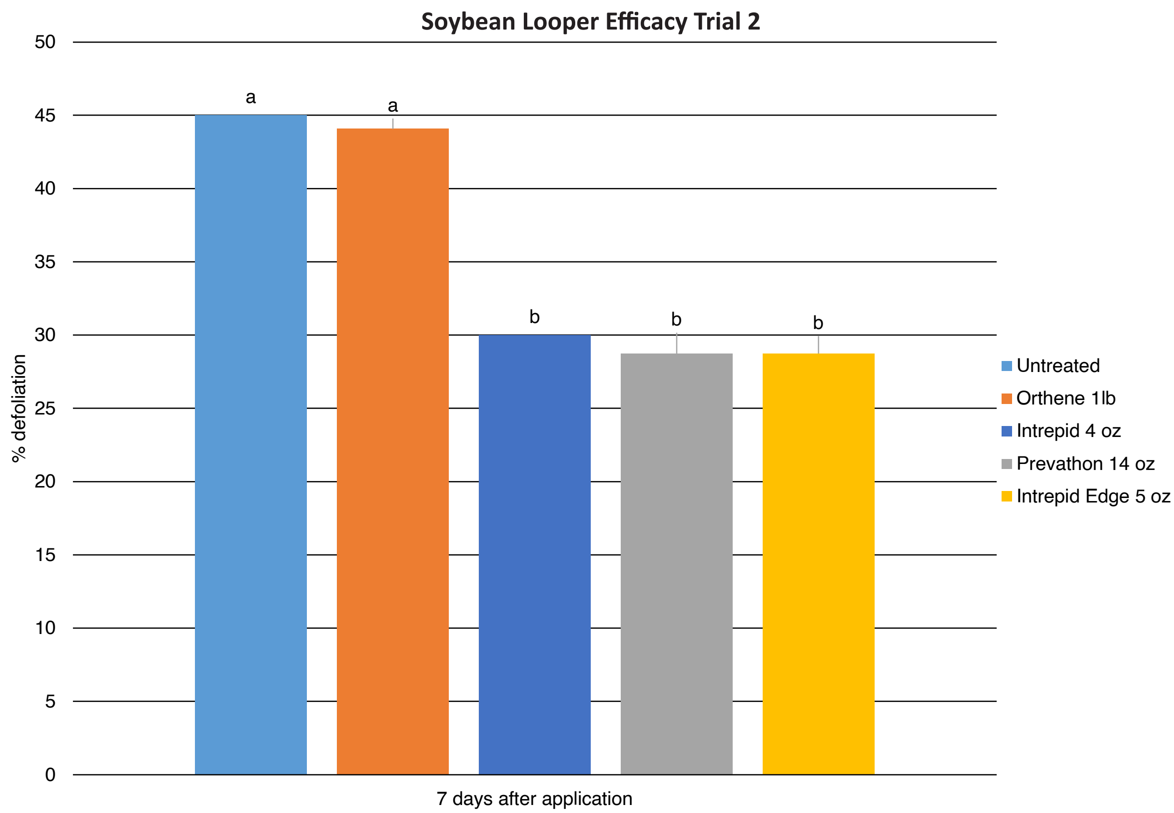

Fig. 5. Results comparing selected insecticides for control of soybean looper in Arkansas in 2019, defoliation ratings 7 days after application.

Efficacy and Residual Control of Selected Insecticides for Corn Earworm, *Helicoverpa zea*, in Soybean, *Glycine max*

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Abstract

Field trials were conducted during the 2018 and 2019 growing season to evaluate the control of several insecticides for control of corn earworm in soybean. While most of the insecticides provided adequate control at 3 and 6 days after treatment, the products containing chlorantraniliprole were the only ones that provided control beyond 15 days. Lambda was the only treatment that did not reduce corn earworm densities below the threshold at any sampling date.

Introduction

Corn earworm, *Helicoverpa zea* (Boddie) (CEW), is the most economically important insect pest of soybean, [*Glycine max* (L.) Merr.], in Arkansas (Musser et al. 2016, 2017, 2018, 2019). Corn earworm in Arkansas usually undergoes 5 generations per year. The first generation typically occurs on wild hosts such as crimson clover, *Trifolium incarnatum* L., with the subsequent generation moving into corn, *Zea mays* L. Host preference of corn earworm is positively correlated to plant maturity, and corn earworm strongly prefers plants in the flowering stage with corn being the most suitable of all hosts (Johnson et al. 1975). Once corn begins to senesce, it becomes unattractive to corn earworm adults as an ovipositional host. The third and fourth generations generally occur in other agronomic host crops such as soybean, cotton, *Gossypium hirsutum* L., and grain sorghum, *Sorghum bicolor* L. Moench, with the fifth generation occurring primarily on volunteer crop plants after harvest and other non-crop wild hosts (Hartstack et al. 1973). The purpose of these trials was to evaluate the control of corn earworm with selected insecticides and determine which insecticides provided residual control over an extended time.

Procedures

Trials were conducted on grower fields in 2018 and 2019. The plot size was 12.5-ft (4 rows) by 40-ft. Plot design was a randomized complete block with 4 replications. In 2018, a grower in Lonoke County planted cultivar Asgrow 46X6 on 38-in. rows on 25 May, and the application was made 25 July. The growth stage was R3–R4 at the time of application (Table 1). In 2019, a grower in Prairie County planted cultivar Stine 51LE20 on 22 June, and the application was made 19 Aug. (Table 2). The growth stage was R3 at the time application was made. Applications were made using a Mudmaster high clearance sprayer fitted with 80-02 dual flat fan nozzles at 19.5-in. spacing with a spray volume of 10 gal/ac, at 40 psi.

Plots were evaluated at 3, 6–7, and 15–16 days after application (DAA) by making 25 sweeps per plot with a standard 15-in. diameter sweep net. The data was processed using Agriculture Research Manager (Gylling Data Management, Inc., Brookings, S.D.) and Duncan's New Multiple Range Test ($P = 0.10$) to separate means.

Results and Discussion

Soybean Bollworm Efficacy Trial, 2018. At 3 DAA, the untreated check averaged 58 larvae/ 25 sweeps, over 5 times threshold of 9 larvae/25 sweeps (Fig. 1). All treatments reduced CEW numbers below the untreated check, although Lambda failed to reduce numbers below the threshold of 9 larvae per 25 sweeps. At 6 DAA, all treatments were less than the untreated check; however, Lambda again failed to reduce numbers below the threshold. At 16 DAA, only Besiege® and Prevathon® at either of the rates kept CEW numbers below the threshold. No other treatments were different than the untreated check except Lambda plus Acephate, which had significantly more larvae than the untreated check.

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Soybean Corn Earworm Efficacy Trial, 2019. At 3 DAA, the untreated check averaged 15 larvae/25 sweeps, 1.5 times threshold of 9 larvae/25 sweeps. All treatments reduced CEW numbers below the untreated check. At 6 DAA, all treatments had fewer CEW than the untreated check. Vexer®, Vexer + Experimental, and Denim® at 12 oz did not reduce CEW below the threshold of 9 larvae/25 sweeps. At 15 DAA, Denim at both rates, Vexer + Experimental, and Vexer + Reveal Endurex® failed to control CEW compared to the untreated check. Intrepid Edge® had better residual control at 15 DAA in 2019 than it did in 2018; however, there was a lot less pressure.

Practical Applications

While all of the treatments in both trials provided some level of control for corn earworm at 3 and 6 DAA, only the treatments which contained chlorantraniliprole (Besiege and Prevathon) protected the crop past 6 DAA. In Arkansas, multiple generations of CEW in the same field are common. These studies show that a single application of a long residual product may be a more cost-effective option for corn earworm compared to multiple applications of short residual products.

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Table 1. Soybean Bollworm Efficacy Trial, 2018 treatment list.

Treatment	Active ingredient	Rate per acre
Besiege®	Chlorantraniliprole; lambda-cyhalothrin	7 oz; 9 oz
Prevathon®	Chlorantraniliprole	14 oz; 18 oz
Intrepid Edge®	Spinetoram; methoxyfenozide	3.5 oz; 5 oz
Steward®	Indoxacarb	12 oz
Denim®	emamectin benzoate	8 oz; 12 oz
Lambda®	lambda-cyhalothrin	1.82 oz
Lambda plus Acephate	lambda-cyhalothrin + acephate	1.82 oz and 0.5 lb respectively

Table 2. Soybean Bollworm Efficacy Trial, 2019 treatment list.

Treatment:	Active ingredient	Rate per acre
Denim®	emamectin benzoate	8 oz; 12 oz
Besiege®	Chlorantraniliprole; lambda-cyhalothrin	10 oz
Prevathon® plus Brigade®	chlorantraniliprole + bifenthrin	19.2 oz and 6.39 oz, respectively
Intrepid Edge®	spinetoram + methoxyfenozide	5 oz
Vexer®	methoxyfenozide	6 oz
Vexer + Experimental	methoxyfenozide + experimental	6 oz and 8 oz, respectively
Vexer + Reveal®	methoxyfenozide + bifenthrin	6 oz and 6.4 oz, respectively

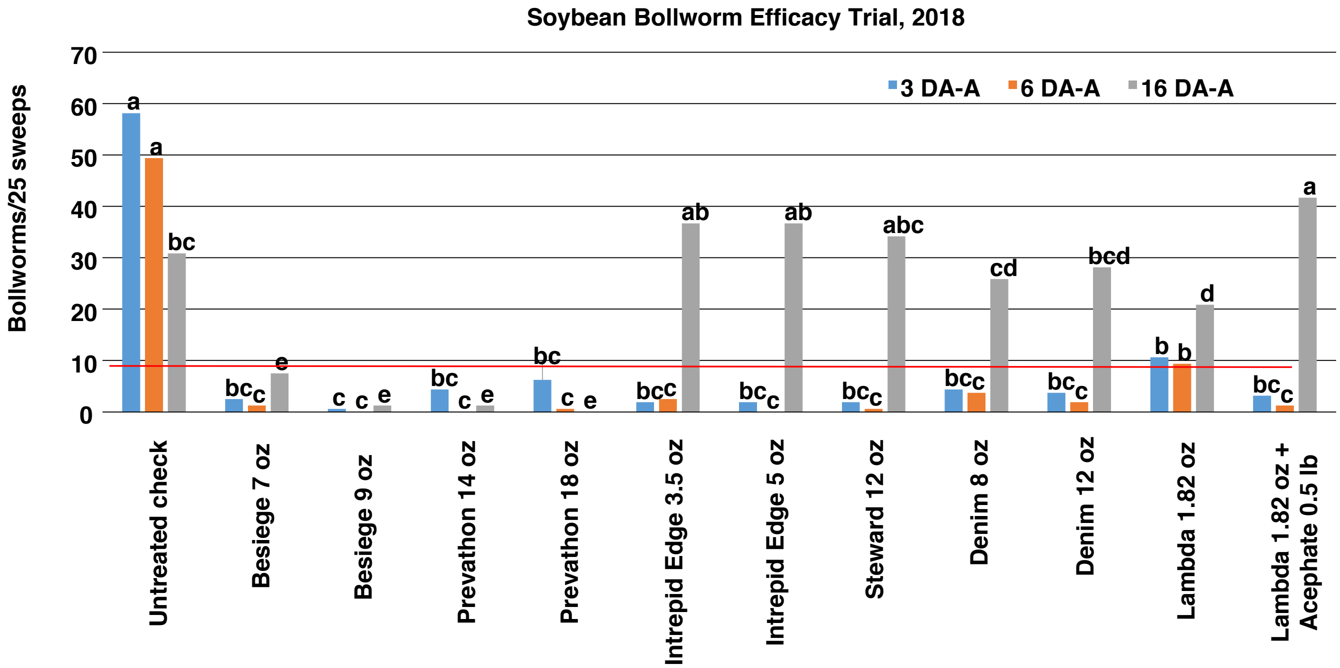

Fig. 1. Soybean Bollworm Efficacy Trial, 2018 showing the mean number of corn earworm per 25 sweeps for selected insecticides treatment at 3, 6, and 16 days after application.

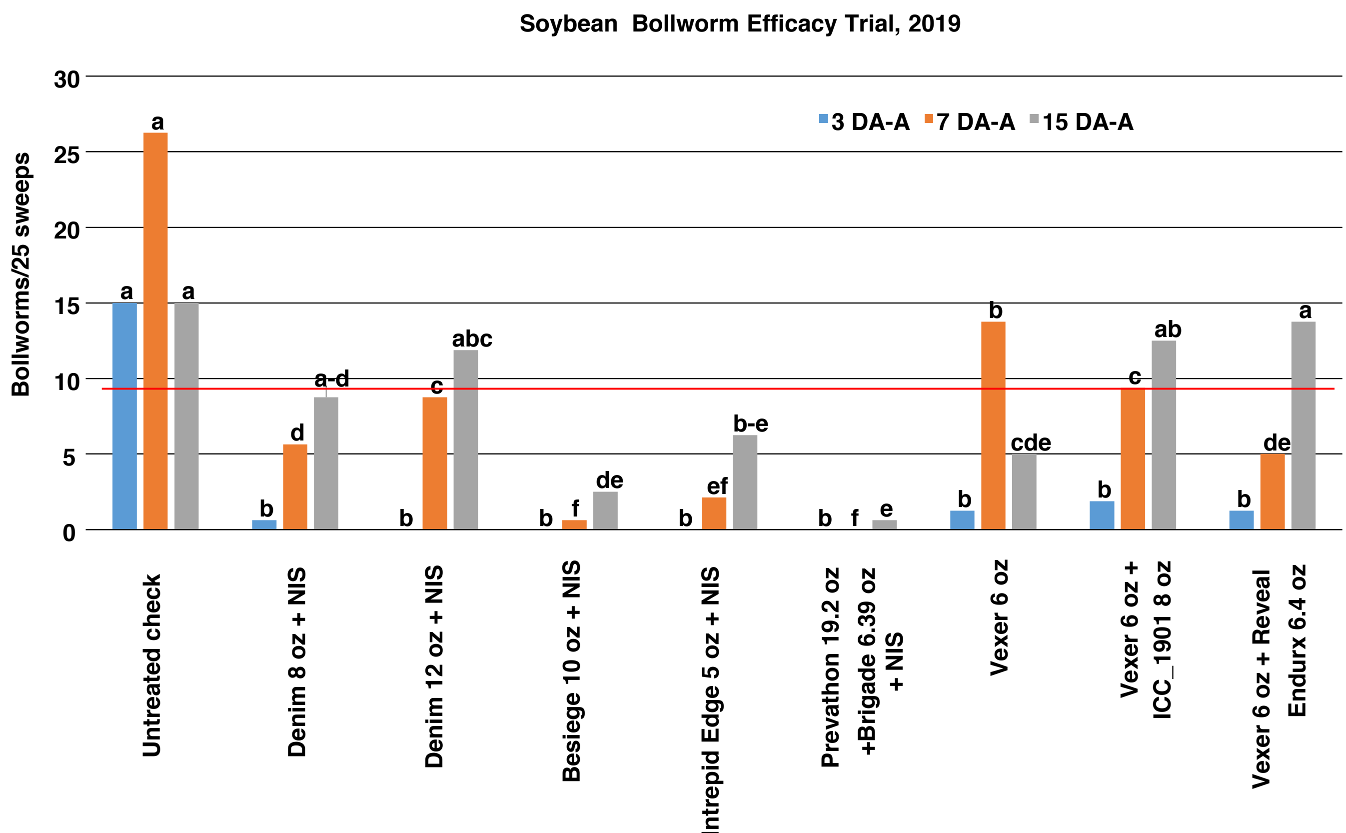

Fig. 2. Soybean Bollworm Efficacy Trial, 2019 showing the mean number of corn earworm per 25 sweeps for selected insecticides treatment at 3, 7, and 15 days after application.

Insecticide Seed Treatment Performance on Soybean Planted into Cover Crops

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Abstract

Cover crop acreage has become increasingly adopted in recent years to improve soil quality, suppress weeds, and reduce nutrient loss; however, they can also harbor insect pests. An effective way to combat many of these pests is the use of an insecticide seed treatment. Three soybean insecticide seed treatments were evaluated against a fungicide only check, then planted into 3 cover crops and a fallow block. Throughout the growing season, low densities of insect pests were observed in the study. Plots with an insecticide seed treatment yielded an average of 2.1 bu./ac greater than those containing fungicide-only treated seed.

Introduction

Cover crops have been implemented on a considerable amount of acreage in Arkansas to improve soil quality, suppress weeds, and reduce nutrient loss (Roberts et al., 2018a; 2018b; 2020). Although there are documented benefits of using cover crops, there are also some drawbacks, one of which is the harboring of insect pests. Some problematic insect pests for soybean planted behind cover crops include wireworms, pea leaf weevil, stinkbugs, cutworms, and armyworms. From an insect management standpoint, terminating the cover crop 3–4 weeks before planting the commodity crop is the best management practice. However, to get the most out of a cover crop, in terms of biomass for organic matter and ground cover for weed suppression, growers may opt to plant into a green cover crop or terminate just before planting. Foliar insecticides are an option for controlling insect pests but can be ineffective in fields where a cover crop has produced a thick "mat" that impedes insecticide penetration. Currently, it is recommended that growers use an insecticide seed treatment when planting into a cover crop. This study evaluated multiple soybean insecticide seed treatments across several cover crops to assess their value to growers.

Procedures

A study was conducted in Marianna, Ark. at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station to evaluate the use of insecticide seed treatments in multiple cover crops. A field was split into four blocks containing a fallow block and three cover crop blocks including cereal rye, Austrian winter pea, and a blend (Balansa fixation clover, winter wheat, crimson clover, oats, purple top turnip, triticale, Daikon radish, and cereal rye; Cattleman's Treasure, Stratton Seed, Stuttgart, Ark.) planted on 25 Oct. Cover crops were terminated by herbicide application and rolling on 17 May, 4 days before planting. Three insecticide seed treatments were evaluated including; Cruiser Maxx® 3.2 oz/ac, Cruiser Maxx Beans 3.2 oz/ac + Avicta® 3 oz/ac, Cruiser Maxx Beans 3.2 oz/ac + Fortenza® 3 oz/ac, and a fungicide only untreated check (Trilex® 2000). Soybean was planted on 21 May, arranged in a randomized complete block design with four replications. Sweep net samples were taken before planting on 6 May and post-planting on 3 June and 18 June. Plots were harvested on 8 Oct. Data was analyzed using a student t-test with Tukey's honestly significant difference (JMP Pro 14.1, SAS Institute Inc., Cary, N.C.). Differences were considered significant at $P < 0.10$.

Results and Discussion

Large densities of insect pests were not observed in any treatment or any cover crop throughout the growing season. There was no difference in yield based on cover crop and insecticide seed treatment (Fig. 1). However, across all cover crops and the fallow, soybean containing an insecticide seed treatment yielded an average of 2.1 bu./ac greater than the fungicide only ($P < 0.01$) (Fig. 2). Substantial deer feeding occurred to soybean planted within the cover crop blend, so yields were not compared between cover crops.

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Practical Applications

This research assesses the value of insecticide seed treatments in a cover crop situation and will allow growers to make a more informed decision when it comes to seed treatment selection.

Acknowledgments

The authors would like to thank the Arkansas Soybean Promotion Board for funding this project. Support was also provided by the University of Arkansas System Division of Agriculture.

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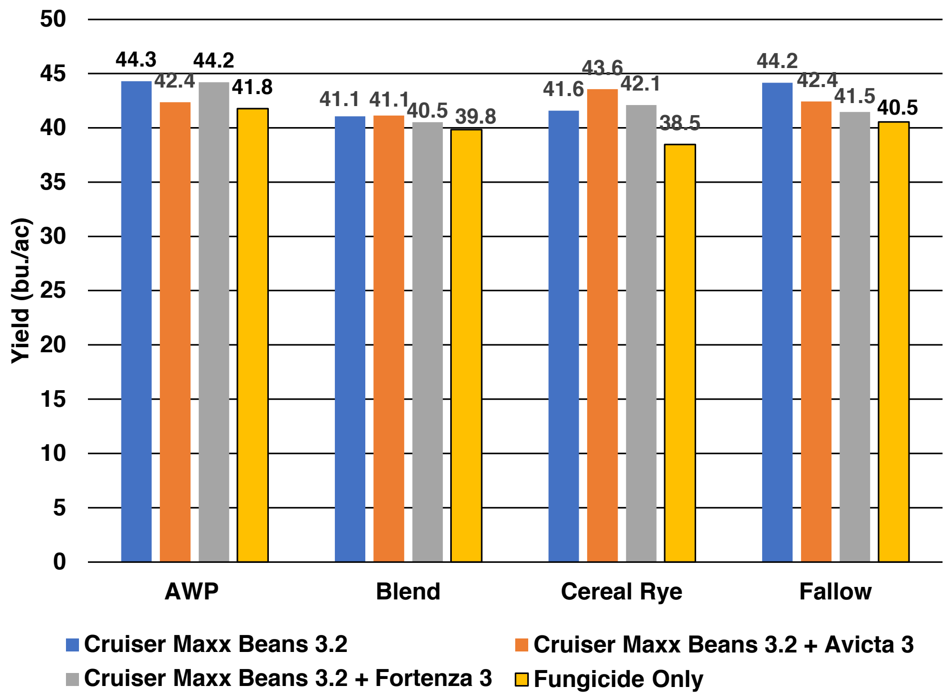

Fig. 1. Yield for soybean seed treatments planted into each cover crop. AWP = Austrian winter pea. Blend = Balansa fixation clover, winter wheat, crimson clover, oats, purple top turnip, triticale, Daikon radish, and cereal rye. The blend is sold commercially as Cattleman's Treasure.

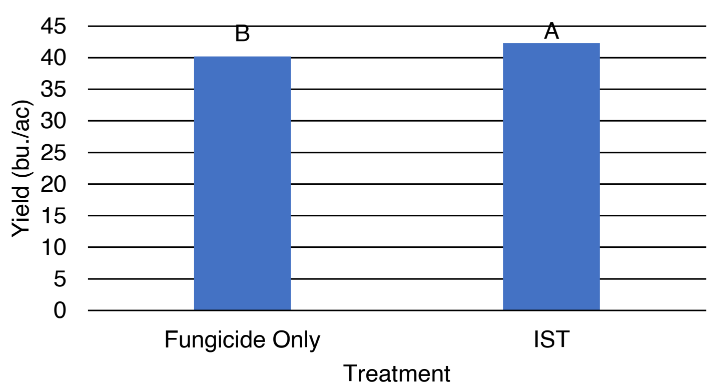

Fig. 2. Insecticide seed treatment yield compared to fungicide only check. Bars with the same letter are not significantly different at *P* = 0.10.

Nozzle Type and Arrangement Effect on Spray Coverage

A.N. McCormick,[1] L.G. Smith,[1] T.W. Dillon,[2] L.M. Collie,[2] B.M. Davis,[2] and T.R. Butts[3]

Abstract

Arkansas row crop producers face many challenges throughout the growing season. One of those challenges includes maintaining necessary spray coverage to achieve optimum levels of weed control. The objective of this research was to evaluate how nozzle arrangement (the direction of emitted spray) and droplet size impact spray coverage. Field experiments were conducted at the University of Arkansas Pine Bluff Small Farm Outreach Center near Lonoke, Arkansas, and at the University of Arkansas System Division of Agriculture's Rohwer Research Station located near Rohwer, Arkansas. They included 9 treatments consisting of 4 nozzle types, 3 arrangements for directional nozzles, and a non-treated control. Water sensitive cards were used to obtain coverage data. No difference was observed in coverage data between sites; therefore, sites were pooled. Coarse spray (AIXR and 3D nozzles) provided better coverage compared to ultra-coarse spray (TTI and ULD nozzles). Results show an alternating pattern across the boom was the most effective and similar to straight down flat fan nozzles (AIXR and ULD) to obtain all-around plant coverage while using directional nozzles (3D and TTI).

Introduction

There is an abundance of nozzle types and designs available for herbicide applications today. Although this provides many options for producers and applicators, it has also left them with many questions. Do certain nozzles improve coverage compared to others? For directional spray nozzles such as the Turbo TeeJet Induction (TTI) (TeeJet Technologies, Wheaton, Ill.), which direction should they face across the spray boom to maximize coverage? How do angled spray nozzles compare with straight flow nozzles in coverage? Fine spray droplets are more sensitive to off-target movement by wind (Hilz and Vermeer, 2012). This can lead to injury of non-resistant crops adjacent to the target area. Increasing the droplet size is an effective way to reduce particle drift deposited downwind, especially in regions nearest the crop (Bueno et al., 2017). With changes in label requirements and spray drift concerns, increasing droplet size has become commonplace, and TTI nozzles have become a more popular selection. However, with such a large droplet size, alternative methods for improving spray coverage must be identified. The objective of this research was to evaluate how nozzle arrangement (the direction of emitted spray) and droplet size impact spray coverage. This research will assist producers and applicators to more effectively set up their spray equipment, thereby improving the efficiency of their herbicide applications through improved spray coverage.

Procedures

Field studies were conducted in the summer of 2019 at the University of Arkansas Pine Bluff Small Farm Outreach Center near Lonoke, Arkansas, and at the University of Arkansas System Division of Agriculture's Rohwer Research Station near Rohwer, Arkansas. At Lonoke, dry-seeded rice was drilled in 7.5-in. row widths. Soybean was planted in 38-in. row widths at the Rohwer location. All applications were made with a Bowman MudMaster. At the time of application, the rice was 8 in. tall and 1–2 tiller and soybean was 21 in. at the R1 growth stage. The experimental design was a randomized complete block with four replications. Treatments consisted of four nozzle types [Air induction extended range (AIXR) and Turbo TeeJet Induction (TTI) (TeeJet Technologies, Wheaton, Ill.), 3D and ultra-low drift (ULD) (Pentair Hypro, New Brighton, Minn.)], three nozzle arrangements along the boom for the directional 3D and TTI nozzles (all forward, all backward, and alternating), and a non-treated control. This provided a total of 9 treatments. Nozzle orifice sizes, spray pressures, and sprayer speeds were selected for each treatment to maintain the correct 10 gallons per acre (GPA) spray volume while creating similar droplet size classifications between comparable nozzles. The AIXR and 3D nozzles produced a coarse spray, while the ULD and TTI nozzles produced an ultra-coarse spray. Data collection consisted of three water-sensitive paper spray cards (Syngenta,

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Greensboro, N.C.) per plot: a horizontal card at the top of the canopy (top), a vertical card facing towards the direction of the sprayer (front), and a vertical card facing away from the direction of the sprayer (back). The spray cards were placed 4–6 in. from the soil surface on collection platforms that were mounted to rebar posts near the center of each plot. Spray cards were initially a bright yellow color, but once any wet substance came into contact with the card, they turned blue. Water sensitive cards were analyzed for spray coverage using DepositScan from the USDA-ARS Application Technology Research Unit (Wooster, Ohio). Coverage data were then subjected to analysis of variance using SAS v. 9.4 (SAS Institute, Cary, N.C.), and means were separated using Fisher's protected least significant difference test at $\alpha = 0.05$.

Results and Discussion

Results indicated no difference in spray coverage between sites; therefore, data from Rohwer and Lonoke sites were combined. Although two different cropping systems were utilized at each site (rice in Lonoke and soybean in Rohwer), the agronomic practices utilized resulted in little plant material that intercepted spray before reaching the water-sensitive paper. Rice was only approximately 4–6 in. tall, and soybean was planted in 38-in. row widths with the application before canopy closure; therefore, the spray cards were uninhibited. Results of the combined data showed there was an interaction between water-sensitive card location and nozzle arrangement and a significant main effect of nozzle type. Initial results indicated that greater spray coverage was achieved with the AIXR and 3D nozzles compared to the ULD and TTI nozzles (Fig. 1). This is due to the AIXR and 3D nozzles emitting smaller droplet sizes and, therefore, a greater number of droplets in the fixed sprayed volume were available to impact the spray card compared to the ULD and TTI nozzles. All nozzle arrangements achieved similar coverage on the top card location (Figs. 2 and 3). Forward spraying nozzles achieved adequate coverage on top and front cards but provided little coverage on the back card (Figs. 2–5). Backward spraying nozzles provided good coverage of top and back cards, but little coverage on the front card (Figs. 2–5). Both backward and forward nozzle arrangements resulted in uneven whole plant coverage. Whereas the alternating nozzle arrangement for the directional 3D and TTI nozzles provided overall more uniform spray coverage on the top, front, and back of the collection surfaces compared to the other nozzle arrangements and was similar to that of the straight-down spray emission of the AIXR and ULD nozzles (Figs. 2–5).

Practical Applications

Overall, this research highlighted differences in spray coverage were achieved based on the nozzle selection and arrangement. The smaller droplet size producing nozzles (AIXR and 3D) provided greater coverage than larger droplet size producing nozzles (TTI and ULD). If applicators are spraying in a specific area where drift is less of a concern, using these smaller droplet size producing nozzles may improve overall weed control. Additionally, applicators may achieve better weed control through enhanced and more all-around uniform spray coverage by implementing the alternating nozzle arrangement across the spray boom when using directional nozzles such as the 3D and TTI nozzles.

Acknowledgments

The authors would like to thank the Arkansas Soybean Promotion Board, Arkansas Rice Research and Promotion Board, University of Arkansas System Division of Agriculture, Pentair Hypro, and TeeJet Technologies for funding and support of this research.

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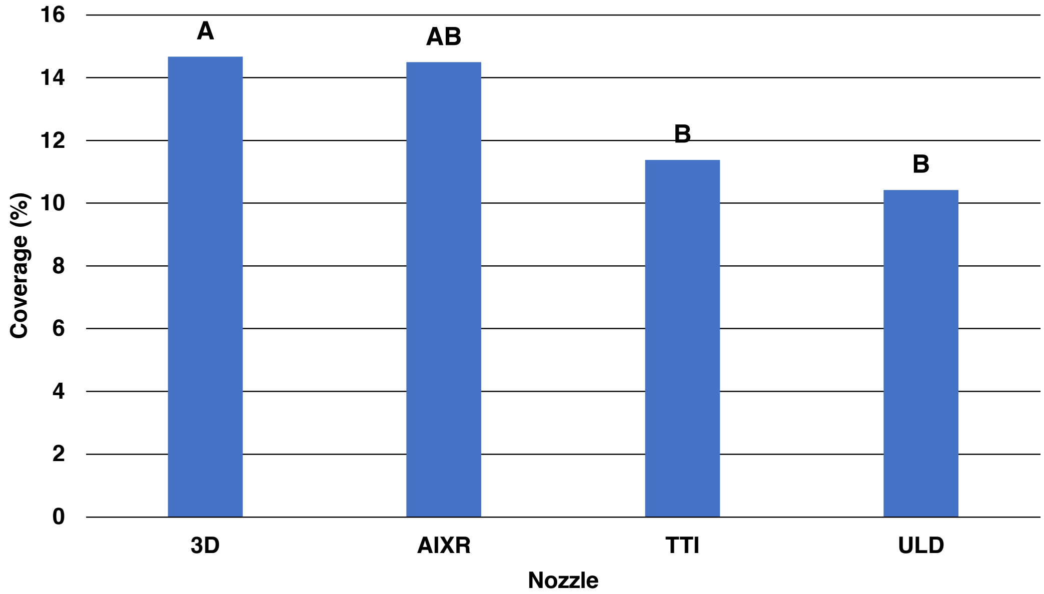

Fig. 1. Effect of nozzle type on spray coverage. Treatments with the same uppercase letter are not significantly different according to Fisher's protected least significant difference test at α = 0.05. AIXR = air induction extended range; TTI = Turbo TeeJet Induction; ULD = Ultra-low drift.

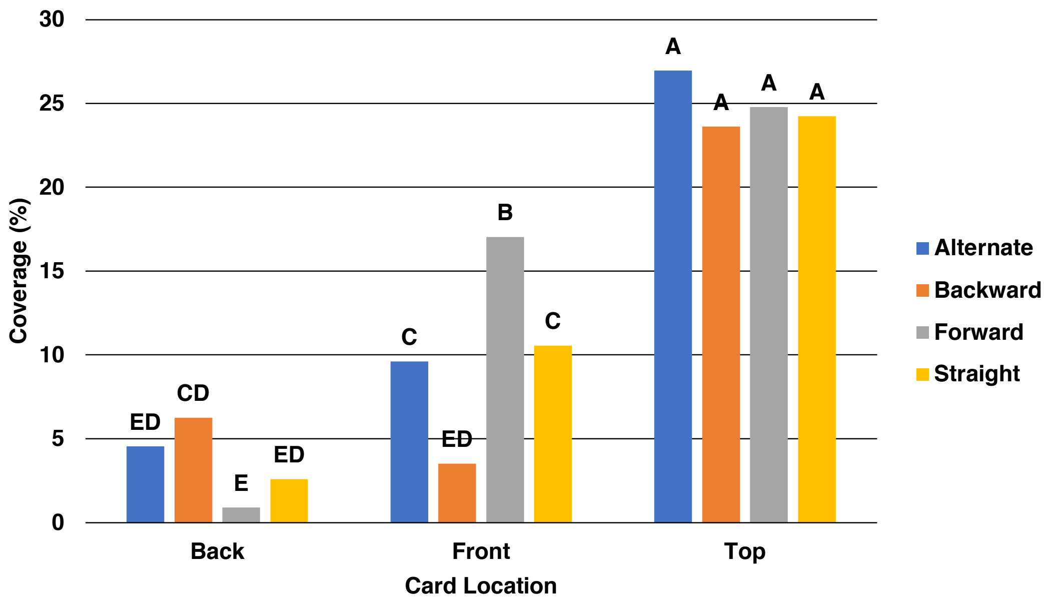

Fig. 2. Effect of a card location (Back, Front, Top) by nozzle arrangement interaction on spray coverage. Treatments with the same uppercase letter are not significantly different according to Fisher's protected least significant difference test at α = 0.05.

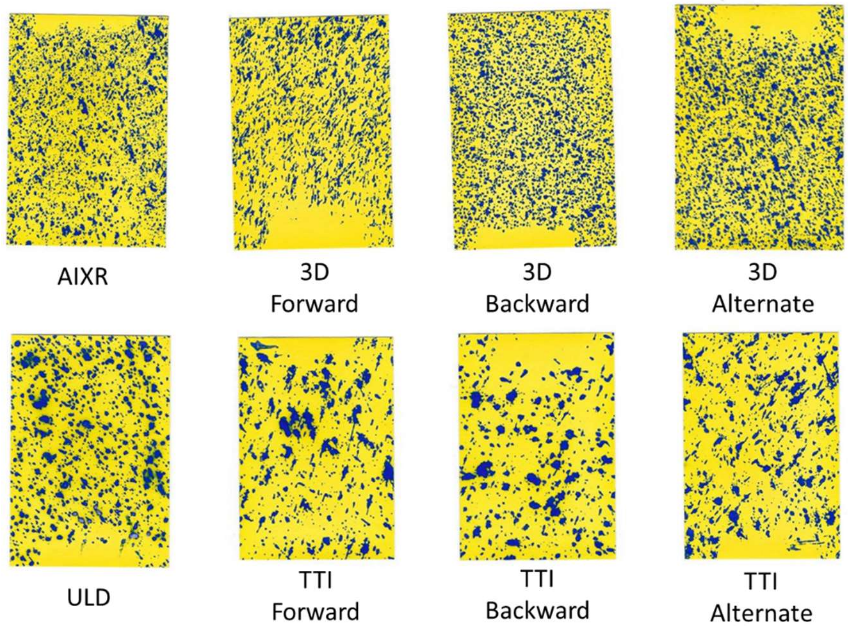

Fig. 3. Top spray cards with coverage affected by nozzle type and arrangement. AIXR = air induction extended range; TTI = Turbo TeeJet Induction; ULD = Ultra-low drift.

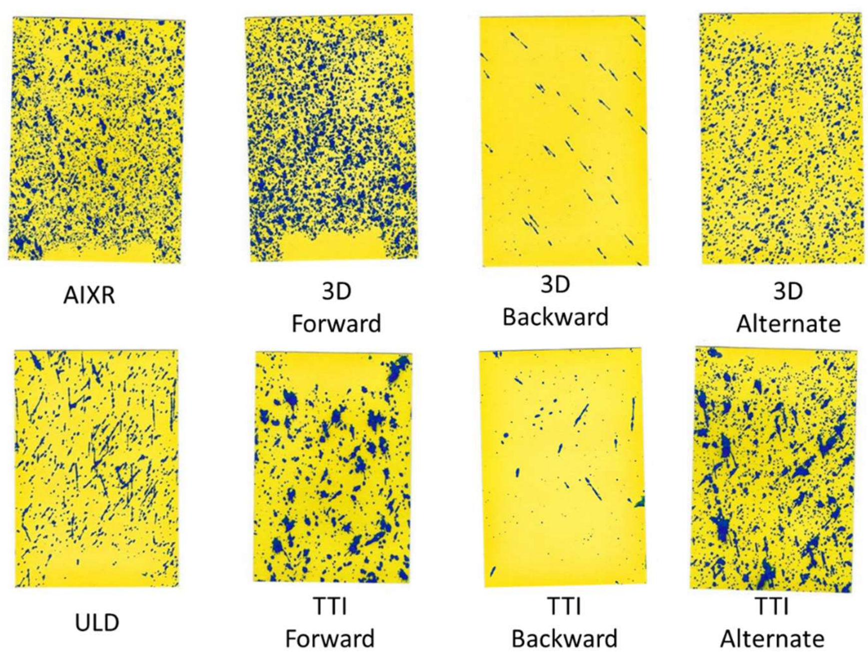

Fig. 4. Front spray cards with coverage affected by nozzle type and arrangement. AIXR = air induction extended range; TTI = Turbo TeeJet Induction; ULD = Ultra-low drift.

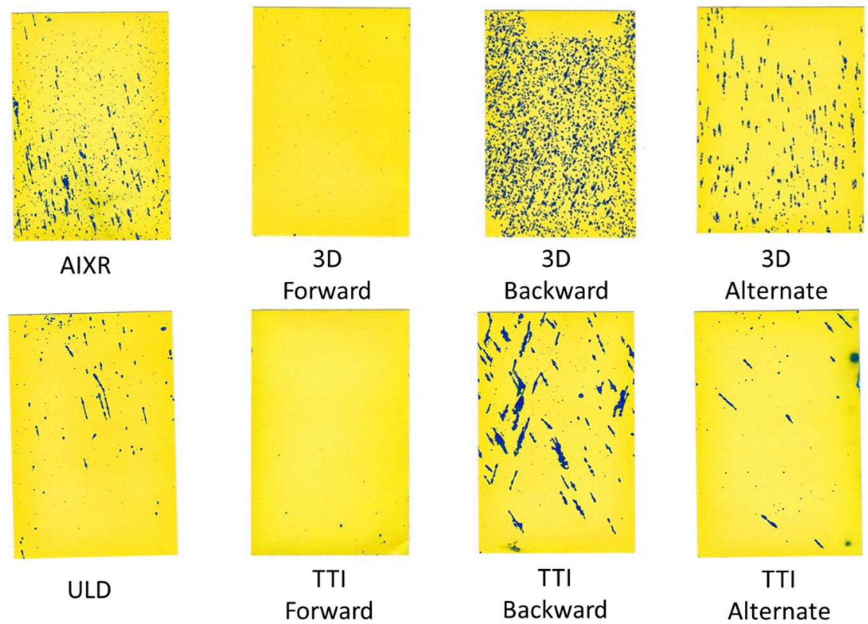

Fig. 5. Back spray cards with coverage affected by nozzle type and arrangement. AIXR = air induction extended range; TTI = Turbo TeeJet Induction; ULD = Ultra-low drift.

Nozzle Type Effect on Coverage and Canopy Penetration using Enlist One® and Liberty™ in Enlist E3™ Soybean

A.N. McCormick,[1] L.G. Smith,[1] T.W. Dillon,[2] L.M. Collie,[2] B.M. Davis,[2] and T.R. Butts[3]

Abstract

Many variables influence the effectiveness of herbicide applications in production agriculture. Applicators need to understand how nozzle selection can impact these variables, especially for the particular herbicide being used. The objective of this research was to evaluate how droplet size and nozzle type (single-fan versus dual-fan) impact spray coverage and canopy penetration from 2-4-D choline (Enlist One®) and glufosinate (Liberty™) herbicides. Field experiments were conducted at the University of Arkansas System Division of Agriculture's Rohwer Research Station, near Rohwer, Ark., and the Newport Extension Center near Newport, Ark., in soybean. A total of 13 treatments consisted of four nozzle types (AIXR, AITTJ60, TTI, and TTI60), three chemical treatments (Enlist One, Liberty, and Enlist One plus Liberty tank-mixture), and a non-treated control. Initial results indicated nozzle type did not influence spray coverage to a large extent; therefore, the single-fan nozzles achieved similar coverage as the dual-fan nozzles evaluated in this research. Greater coverage was achieved on the top canopy cards at Newport compared to Rohwer due to a greater spray volume used at the former site. However, greater coverage on the within canopy cards was achieved at Rohwer compared to Newport, most likely due to the wider row spacing at Rohwer, allowing for droplets to deposit between rows easier. Additionally, spray coverage was greatest with Liberty herbicide, followed by Enlist One plus Liberty and Enlist One alone, respectively. This is likely due to the Liberty herbicide formulation generating a smaller droplet size compared to Enlist One. Factors such as droplet size and agronomic characteristics played a greater role in spray coverage and canopy penetration than the hypothesized single-fan versus dual-fan treatments.

Introduction

In production agriculture, variables such as spray coverage, canopy penetration, and herbicide selection can all impact the effectiveness of herbicide applications. In order to improve weed control, spray applications must cover the greatest per unit area on the target to be most effective. To optimize spray applications, nozzle companies have developed new designs that seek to provide the greatest and most uniform coverage per target unit area (Ferguson et al., 2016b). Those innovations have prompted questions about how single-fan nozzles compare to dual-fan nozzles in coverage and droplet size. With the abundance of soybean herbicide trait technologies available, it is possible soybean fields grown adjacent to each other will not be resistant to similar herbicides and will be susceptible to injury and yield loss from off-target spray movement (Legleiter and Johnson, 2016). Label requirements have forced changes to nozzle types that emit coarser droplets to reduce physical drift. Droplet size should be large enough to reach the weed without moving off-target and small enough to provide effective coverage on the plant. Poor control and the potential for herbicide-resistant weeds occurs when coverage is not adequate, and previous research has demonstrated reduced efficacy with coarser droplet sizes using both 2,4-D plus glyphosate (Enlist Duo®) and glufosinate (Liberty™) herbicides (Butts et al. 2018; 2019). Results from a study by Ferguson et al. (2016b) showed that applicators could select a coarser droplet size classification without observable loss in coverage while reducing the drift potential of the application when using dual-fan nozzles. This not only prevents injury to adjacent crops but reduces the establishment of resistance-prone weeds on field borders. Herbicide drift exposure rapidly selected for *Amaranthus* spp. biotypes with reduced herbicide sensitivity over two generations (Vieira et al., 2020). Additionally, canopy penetration is important to ensure that smaller weeds below the crop canopy are killed before they reach sizes beyond herbicide control and cause crop yield loss. Both spray drift reduction and improved canopy penetration have been achieved previously with proper nozzle selection and application setup (Ferguson

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et al., 2016a). The objective of this research was to evaluate how droplet size and nozzle type (single-fan versus dual-fan) impact spray coverage and canopy penetration from 2-4-D choline (Enlist One®) and glufosinate (Liberty) herbicides.

Procedures

Field studies were conducted in the summer of 2019 at the University of Arkansas System Division of Agriculture Rohwer Research Station near Rohwer, and the Newport Extension Center near Newport. At the Rohwer site, soybean was planted in 38-in. row widths, and at the Newport site, soybean was drilled seeded in 7.5-in. row widths. All applications were made with a Bowman MudMaster. At the time of application, soybean at the Rohwer site was 21 inches and R1 growth stage. Soybean at the Newport site was 24 inches and R2 when the application was made. The experimental design was a randomized complete block with four replications. Treatments consisted of four nozzle types [Air Induction Extended Range (AIXR), Air Induction Turbo Twin Jet (AITTJ60), Turbo TeeJet Induction (TTI), and Turbo TeeJet Induction TwinJet (TTI60) (TeeJet Technologies, Wheaton, Ill.)], three chemical treatments [2,4-D choline (Enlist One) (Corteva AgriSciences, Wilmington, Del.), glufosinate (Liberty) (BASF Corporation, Florham Park, N.J.), and 2-4-D choline (Enlist One) + glufosinate (Liberty) tank-mixture], and a non-treated control. This provided a total of 13 treatments. Treatments were applied in 10 gallons per acre (GPA) spray volume at Rohwer and 15 GPA spray volume at Newport. The nozzle types were selected to allow comparisons between single-fan (AIXR and TTI) and dual-fan (AITTJ60 and TTI60) nozzles. The emitted droplet size was similar between the AIXR and AITTJ60 nozzles (very coarse) and between the TTI and TTI60 nozzles (ultra coarse). Data collection consisted of three water-sensitive paper spray cards (Syngenta, Greensboro, N.C.) located at two locations within the canopy for a total of six spray cards per plot. At the top of the canopy, cards were oriented as follows: a horizontal card (top), a vertical card facing towards the direction of the sprayer (front), and a vertical card facing away from the direction of the sprayer (back). The same three card directions were placed within the soybean canopy, 4–6 in. from the soil surface on collection platforms mounted to rebar stakes near the center of each plot. Spray cards were initially a bright yellow color, but once any wet substance came into contact with the card, they turned blue. Water sensitive cards were analyzed for spray coverage using DepositScan from the USDA-ARS Application Technology Research Unit (Wooster, Ohio). Coverage data were then subjected to analysis of variance using SAS v. 9.4 (SAS Institute, Cary, N.C.), and means were separated using Fisher's protected least significant difference test at $\alpha = 0.05$.

Results and Discussion

Results showed an effect of card location (top, front, back) by canopy location (TOP, MID) interaction on spray coverage between sites. This was due to the greater spray volume used at Newport, resulting in greater coverage on the top canopy cards (TOP) compared to the Rohwer site when averaged across nozzle types (Fig. 1). However, greater coverage on the within canopy cards (MID) was achieved at Rohwer most likely due to the wide row widths allowing spray droplets to deposit uninhibited lower in the canopy compared to the drilled soybean in Newport (Fig. 1). Therefore, droplets penetrated the canopy easier, even with a reduced total spray volume. At the Newport site, greater coverage was achieved from the herbicide treatments in the order of Liberty > Enlist One plus Liberty > Enlist One when averaged across all other factors (Fig. 2). This is likely due to changes in droplet size from herbicide formulations as Liberty produces a finer spray than Enlist One. The same trend in spray coverage from herbicide formulations was observed at the Rohwer site; however, it was part of a significant herbicide solution by card location by nozzle type three-way interaction averaged across canopy locations (Figs. 3, 4, and 5). As a result, the nozzle type effect on spray coverage was highly variable at the Rohwer site. For example, coverage was similar at the top card location between the TTI60, AIXR, and AITTJ60 when using Enlist One. Conversely, TTI nozzles produced less coverage at the top card location using Enlist One, but greater coverage when using Liberty or Enlist One + Liberty on the top card location (Fig. 3, 4, and 5). No discernable trend in spray coverage on the front and back card locations was observed regarding the single-fan versus dual-fan nozzles across herbicide solutions at the Rohwer site. Similarly, nozzle type did not influence spray coverage when averaged across all other factors at the Newport site (Fig. 6).

Practical Applications

This research indicated the tested dual fan nozzles (AITTJ60 and TTI60) did not provide greater coverage than their single fan counterparts (AIXR and TTI). Even on the front and back card locations in which directional spray was hypothesized to assist in achieving more all-around uniform coverage, the single-fan nozzles provided similar spray coverage. Instead, factors such as droplet size (from herbicide formulations) and agronomic characteristics (row width) played a greater role in spray coverage. As the dual-fan nozzles evaluated in this research are more expensive than the single-fan nozzles, it is recommended to use either the AIXR or TTI nozzles as they achieve an equal level of spray coverage but would be more economical. Nozzle selection between those two could then be based on spray drift concerns. Results from other research have led to the recommendation of alternating the TTI nozzle spray direction across the boom to achieve optimal coverage.

Acknowledgments

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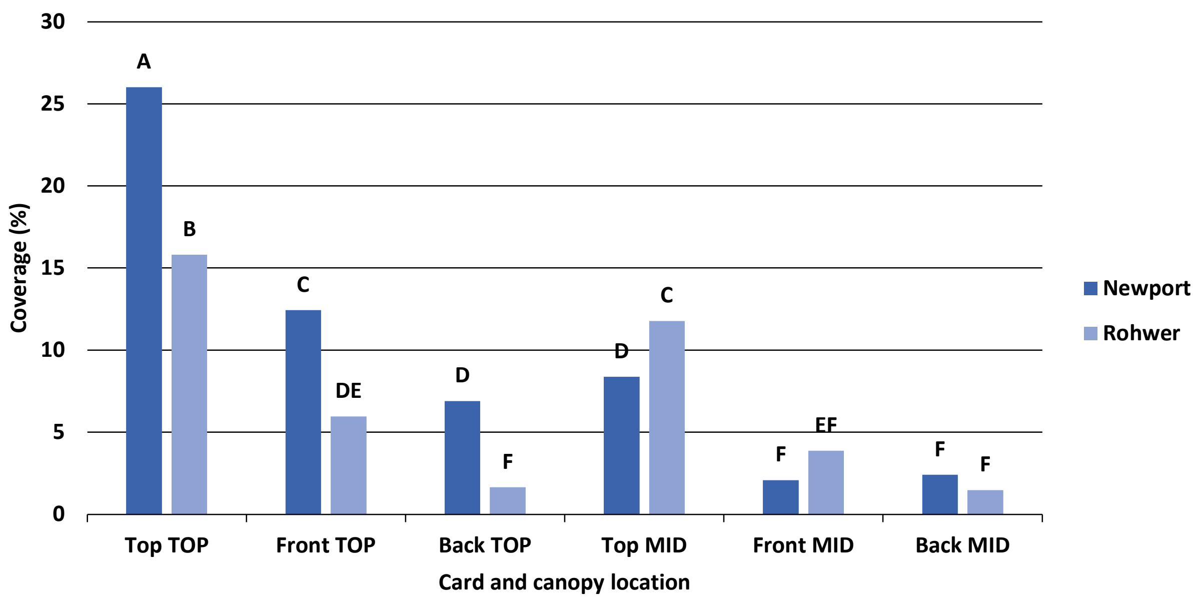

Fig. 1. Effect of a card location (Top, Front, Back) by canopy location (TOP, MID) interaction on spray coverage at the University of Arkansas System Division of Agriculture's Newport and Rohwer Research Station sites averaged across nozzle types. Treatments with the same lowercase letter are not significantly different according to Fisher's protected least significant difference test at α = 0.05.

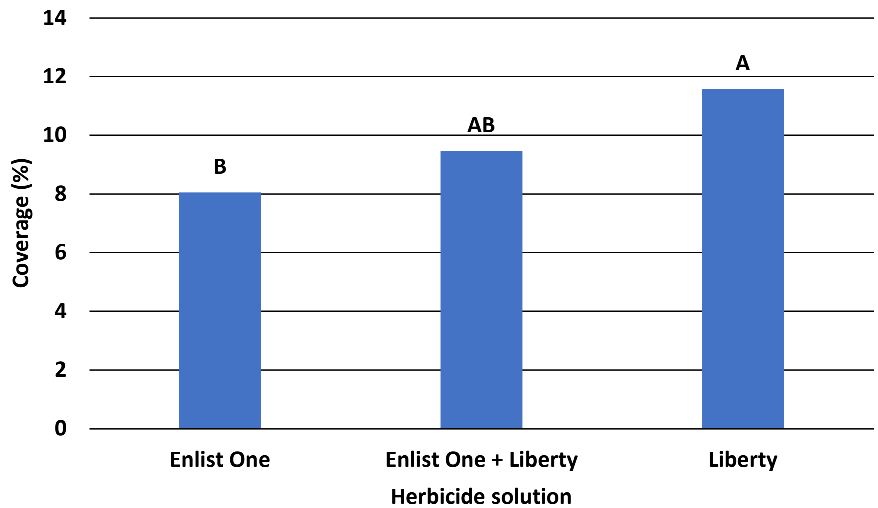

Fig. 2. Effect of herbicide solution on spray coverage at the University of Arkansas System Division of Agriculture's Newport Extension Center site averaged across all other factors. Treatments with the same uppercase letter are not significantly different according to Fisher's protected least significant difference test at α = 0.05.

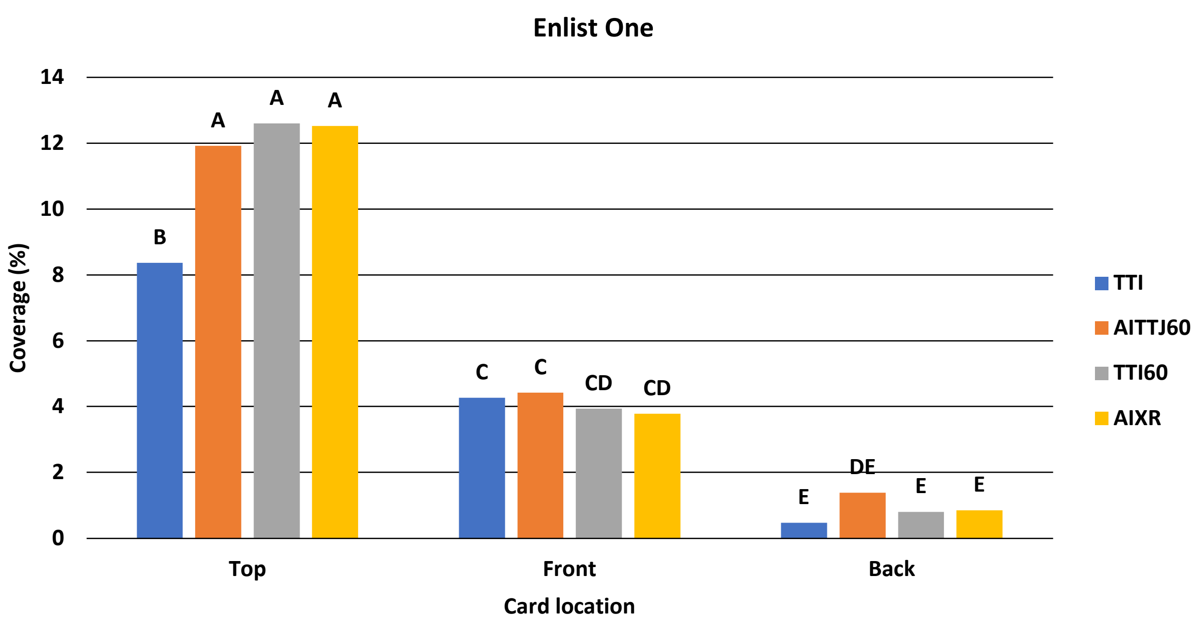

Fig. 3. Effect of a card location by nozzle type interaction on spray coverage with Enlist One herbicide at the University of Arkansas System Division of Agriculture's Rohwer Research Station site averaged across canopy locations. Treatments with the same uppercase letter are not significantly different according to Fisher's protected least significant difference test at α = 0.05.

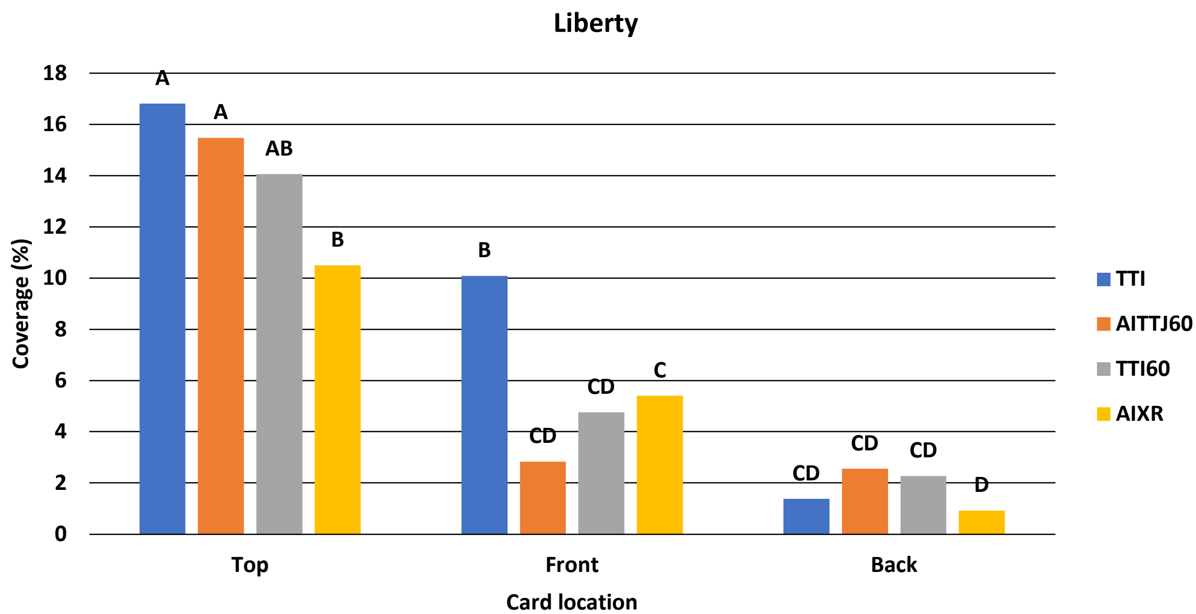

Fig. 4. Effect of a card location by nozzle type interaction on spray coverage with Liberty herbicide at the University of Arkansas System Division of Agriculture's Rohwer Research Station site averaged across canopy locations. Treatments with the same uppercase letter are not significantly different according to Fisher's protected least significant difference test at α = 0.05.

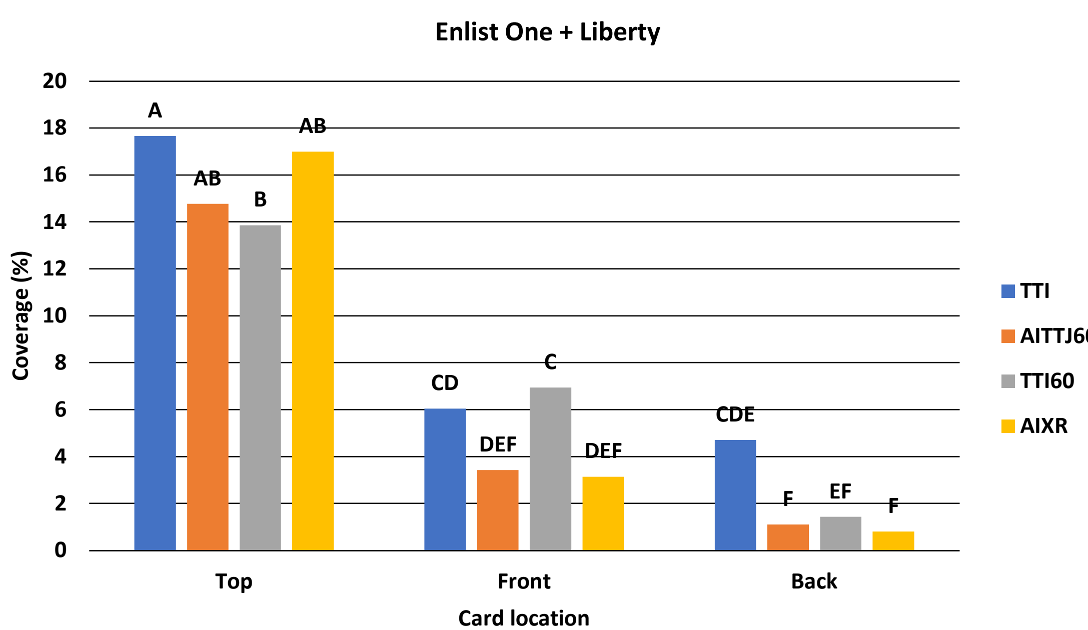

Fig. 5. Effect of a card location by nozzle type interaction on spray coverage with Enlist One + Liberty tank-mixture at the University of Arkansas System Division of Agriculture's Rohwer Research Station site averaged across canopy locations. Treatments with the same uppercase letter are not significantly different according to Fisher's protected least significant difference test at α = 0.05.

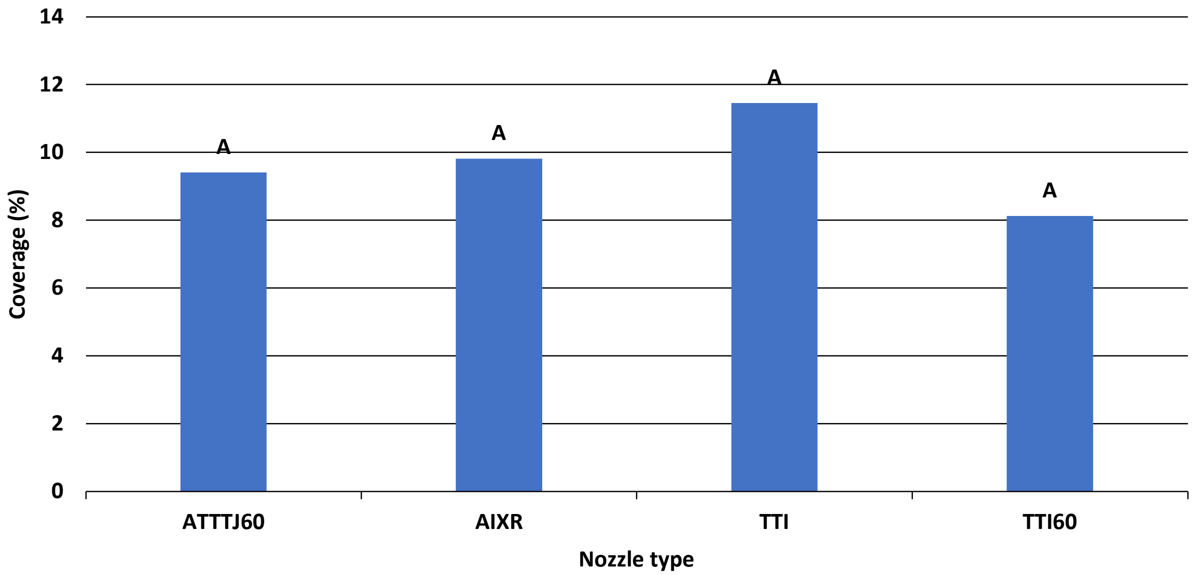

Fig. 6. Effect of nozzle type on spray coverage at the University of Arkansas System Division of Agriculture's Newport Extension Center site averaged across all other factors. Treatments with the same uppercase letter are not significantly different according to Fisher's protected least significant difference test at α = 0.05.

Residual Herbicide Concentrations in an On-farm Water Storage-Tailwater Recovery System in the Cache River Critical Groundwater Area During 2017–2020

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Abstract

Arkansas producers are incorporating tailwater recovery into irrigation systems as a water conservation practice. The water-savings benefits of on-farm water storage-tailwater recovery (OFWS-TWR) systems are recognized, but less is known about pesticide residue dynamics within them. These systems intercept pesticide loads between fields and adjacent waterways, but residual herbicides pose challenges if transported to non-target crops in irrigation or if in the water source used for managed aquifer recharge (MAR). This study monitored concentrations of seven herbicides in an OFWS-TWR system located in the Cache River Critical Groundwater Area over 3 years (April 2017–March 2020). During growing seasons (16 March–15 Sept.), water samples were collected from a storage reservoir and 3 associated tailwater ditches weekly to biweekly, with off-season (16 Sept.–15 March) sampling intervals biweekly to monthly for reservoirs and intermittently for all system components following rain events. The herbicides (2,4-D, clomazone (Command®), dicamba (Clarity®), glyphosate (RoundUp®), metolachlor (Dual®), propanil (Stam®) and quinclorac (Facet®) were targeted for analysis based on producer application records and anticipated regional use patterns. Clomazone, glyphosate, metolachlor, and quinclorac were frequently detected (up to 35%, 55%, 37%, and 98% of samples, respectively) in the OFWS-TWR system. Dicamba, 2,4-D, and propanil were rarely detected (3%, 13%, and 2% of samples, respectively). Herbicide residues were greatest during growing seasons, exhibiting a "spring flush" and reflecting the interaction of herbicide applications and regional precipitation. Herbicide concentrations were greater on average and more variable in the ditches compared to the reservoir. Study findings indicate the risk of non-target crop exposure to herbicide residues in irrigation can be minimized by sourcing irrigation from the reservoir and cycling tailwater through the reservoir for treatment. Reservoirs during the off-season should be used for the water supply source in managed aquifer recharge efforts to ensure groundwater quality protection.

Introduction

The rate of water removal for irrigation from agriculturally important aquifers is unsustainable (Konikow, 2013; Schrader, 2015; Reba et al., 2017). In areas with aquifer depletion, such as the Cache River Critical Groundwater Area (CRCGA), strategies to mitigate groundwater decline include incorporating on-farm water storage tailwater recovery (OFWS-TWR) systems into irrigation practices (Fugitt et al., 2011; Yaeger et al., 2017; Yaeger et al., 2018). Networks of drainage ditches are coupled with storage reservoirs to capture and store runoff and tailwater leaving fields. These systems can replace 25%–50% of a production system's groundwater irrigation on average (Sullivan and Delp, 2012). Further, water stored in reservoirs has been proposed as a suitable water supply for managed aquifer recharge (MAR) (Reba et al., 2017). Other benefits of OFWS-TWR systems include reducing sediment and nutrient loads entering adjacent surface waters (Omer et al., 2018a; Omer and Baker 2019) through flow retention during periods of high precipitation (Czarnecki et al., 2017; Omer et al., 2018b).

Less is known about pesticide residue dynamics in OFWS-TWR systems. Pesticide residues might be similarly reduced within these systems, but could also pose agronomic and environmental challenges. Non-target crop exposures to residues in irrigation containing recycled tailwater could result in yield loss (Willett et al., 2019; Grantz et al., 2020a). Water stored in OFWS-TWR systems must further meet water quality standards to serve as supply water for MAR. But, pesticide residue monitoring in these systems is limited, and sufficient information to assess the real-world potential of adverse outcomes and to develop best management practices is not available. This study monitored concentrations of 7 herbicides over 3 years (April 2017–March 2020) at multiple locations in an

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OFWS-TWR system located in Craighead County, Arkansas, within the CRCGA (Fig. 1).

Procedures

Samples were collected from a storage reservoir and 3 associated ditches in the OFWS-TWR system (Fig. 1). This system supplied and received water to and from surrounding fields, planted primarily in rice and soybean. The first year, samples were collected weekly during the growing season (1 April–15 Sept.) and biweekly during the off-season (16 Sept.–15 March) from all structures. Subsequently, growing season sampling occurred weekly for ditches and biweekly for reservoirs, while off-season sampling occurred monthly for reservoirs and intermittently for all system components after rain events. Producer herbicide application records were collected upon study initiation (April 2017) and updated throughout the growing season. Based on this information and anticipated regional patterns of use, 7 herbicides were selected for analysis: 2,4-D, clomazone (Command®), dicamba (Clarity®), glyphosate (RoundUp®), metolachlor (Dual®), propanil (Stam®) and quinclorac (Facet®). Precipitation was measured at the Arkansas State University campus (weatherdata.astate.edu), approximately 7.5 miles northeast of the study site.

Grab water samples were collected in high-density polyethylene bottles from approximately 1.5-ft depth using a pole sampler, stored on ice, and shipped overnight for processing by the University of Arkansas System Division of Agriculture Residue Laboratory in Fayetteville. Samples were stored at 39 °F until filtration through a 0.45 µm nylon membrane within 48 hr of receipt. Filtered samples were preserved by freezing after separation into aliquots for 1) glyphosate analysis using enzyme-linked immunosorbent assay (ELISA) or 2) analysis of all remaining target herbicides by high performance liquid chromatography with photodiode array detection (HPLC-DAD) following solid phase extraction (SPE). During SPE, samples were acidified to 0.5% phosphoric acid and concentrated from 200 mL into 8 mL 50:50 acetonitrile:methanol eluates using Strata-X reverse-phase polymer columns. Eluates were analyzed using HPLC-DAD with a mobile phase gradient of acetonitrile in 0.1% phosphoric acid ranging from 34%–64% over 20 min. Herbicide concentrations were the product of concentrations measured on the HPLC-DAD considering the ratio of the eluate to the total sample volume. Non-detections or concentrations below thresholds for reliable quantification were reported as less than a reporting limit (i.e. 10 times the detection limit; 2,4-D, propanil, and quinclorac = 0.40 µg/L; dicamba and clomazone = 0.80 µg/L; glyphosate = 0.50 µg/L; metolachlor = 2.0 µg/L). Summary statistics characterizing concentrations by season and site were calculated for frequently detected herbicides.

Results and Discussion

Clomazone, glyphosate, metolachlor, and quinclorac residues were frequently detected in the OFWS-TWR system at levels exceeding reporting limits during the growing season (Table 1; Fig. 2). Dicamba, 2,4-D, and propanil were rarely detected. The concentration maxima of detected herbicides were clustered in April–August each year, congruent with the seasonal comparisons from 7 regional OFWS-TWR systems over one year (Grantz et al., 2020b). This finding reflects a broader trend in agricultural watersheds, in which pesticides are transported from fields to adjacent waterways in a "spring flush" due to coincidence of applications and regional precipitation (Thurman et al., 1991). Specific to the Arkansas delta region, an extensive, multi-year water quality survey recorded 73% of pesticide detections in spring and summer (Senseman et al., 1997).

Study findings also suggest that OFWS-TWR systems could mitigate the effects of the "spring flush" on downstream water bodies by holding tailwater in storage reservoirs. Clomazone, glyphosate, metolachlor, and quinclorac concentrations were greater on average and more variable in the ditches than in the reservoir, most notably when concentrations were at their highest during the growing season (Table 1). This pattern was observed in 7 regional OFWS-TWR systems during a single year (Grantz et al., 2020b) and is congruent with more frequent pesticide detection in streams and rivers in the region, compared to lakes and reservoirs (Senseman et al., 1997). Study findings substantiate the concept that OFWS-TWR systems may intercept pesticide loads, either through removal processes (Moore et al., 2001; Luo and Zhang, 2009) or simply by dilution along the flow path, which occurs in regional river networks (Mattice et al., 2010).

Some study findings deviated from the observed temporal and spatial patterns. Spikes in herbicide concentration, in range with growing season concentrations, occurred during the off-season. A December sample from Ditch 5 contained a glyphosate concentration of 95 µg/L, the greatest concentration observed in the study. Clomazone and quinclorac concentrations were detected in ditch samples in the fall of 2017 and 2019 at elevated levels compared to preceding weeks. In general, quinclorac and glyphosate detections were more frequent outside the growing season compared to clomazone and metolachlor. For glyphosate, this finding may reflect broad-spectrum use in agricultural watersheds (Barber et al., 2020). Quinclorac spikes in the fall could reflect desorption from soil and sediments as rice fields are drained for harvest and, for many fields, maintained under flooded conditions through fall and winter for wildlife habitats. However, quinclorac may also be persistent at low concentrations year-round in OFWS-TWR systems, especially in reservoirs, where median concentrations were similar across seasons.

Practical Applications

Data from this study can be used as a prescreen for herbicide concentrations in recovered tailwater that could lead to cross-crop injuries during the growing season, characterize the quality of water stored in tailwater systems in terms of suitability for artificial groundwater recharge, and estimate herbicide loads intercepted by tailwater recovery systems. Study findings support the following recommendations to minimize the risk of cross-crop contamination when using recovered tailwater for irrigation: 1) irrigation water out of reservoirs will have lower or no detectable residual herbicide concentrations and 2) cycling recovered tailwater through the reservoir facilitates residual herbicide dilution and degradation. More information is needed about how common crops respond to off-target exposure to herbicide residues in irrigation water. It is estimated that dicamba concentrations ranging from 0.05–0.14 mg/L in 3 ac-in. irrigation could reduce yield in soybean (Willet et al., 2019; Grantz et al., 2020a; 2020b). Dicamba was not detected in this study, but concentrations of the detected herbicides were below these levels in the OFWS-TWR system, except for glyphosate concentrations in Ditch 5 in a December 2017 sample. Study findings support guidance to time MAR withdrawals from storage reservoirs during the off-season, particularly winter months (January-February), to preserve groundwater quality.

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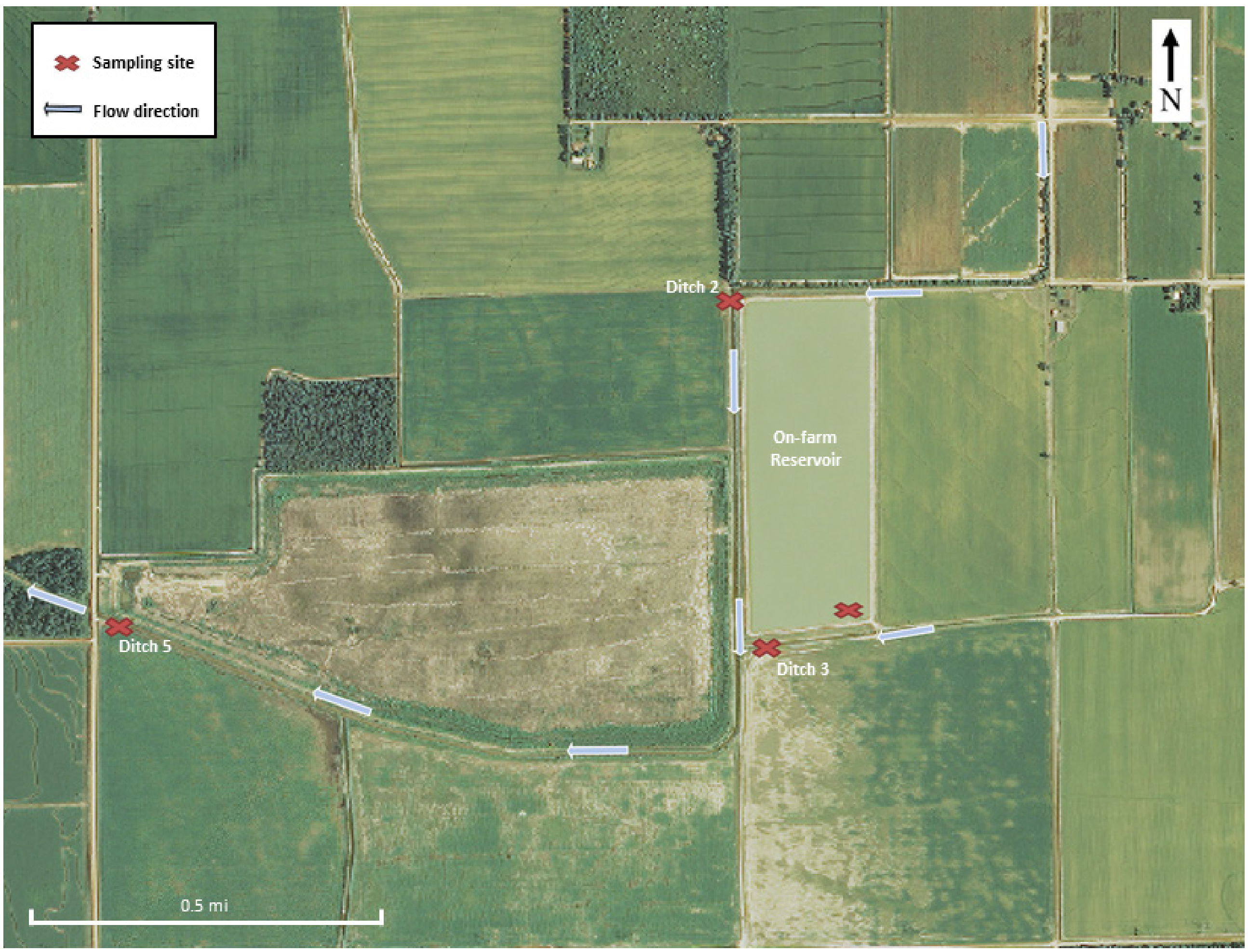

Fig. 1. Map of the monitored on-farm water storage tailwater recovery system in Craighead County, Arkansas.

Table 1. Summary statistics of residual concentrations of the four target herbicides that were frequently detected in the on-farm storage-tailwater recovery system during April 2017–March 2020. Summary statistics were calculated for all data and for data collected during the growing season only.

					Concentration (μg/L)			
ID	**Season**	**Herbicide**	**Count**	**% >RL[a]**	**Median**	**Mean**	**SD[b]**	**Max[c]**
DITCH 2	ALL	Clomazone	73	18	<0.80	1.2	1.4	11
DITCH 3	ALL	Clomazone	71	30	<0.80	1.3	1.6	12
DITCH 5	ALL	Clomazone	82	26	<0.80	1.1	1.0	5.9
RESERVOIR	ALL	Clomazone	85	0	<0.80	<0.80	0	<0.80
DITCH 2	GS[d]	Clomazone	57	21	<0.80	1.2	1.6	11
DITCH 3	GS	Clomazone	55	35	<0.80	1.4	1.8	12
DITCH 5	GS	Clomazone	63	33	<0.80	1.3	1.1	5.9
RESERVOIR	GS	Clomazone	50	0	<0.80	<0.80	0	<0.80
DITCH 2	OS[e]	Clomazone	16	6.3	<0.80	0.93	0.53	2.9
DITCH 3	OS	Clomazone	16	13	<0.80	0.87	0.23	1.7
DITCH 5	OS	Clomazone	19	0	<0.80	<0.80	0	<0.80
RESERVOIR	OS	Clomazone	35	0	<0.80	<0.80	0	<0.80
DITCH 2	ALL	Glyphosate	74	55	0.65	1.3	1.7	12
DITCH 3	ALL	Glyphosate	73	40	<0.50	1.1	2.1	18
DITCH 5	ALL	Glyphosate	85	41	<0.50	2.4	10.5	95
RESERVOIR	ALL	Glyphosate	89	3.4	<0.50	0.52	0.14	1.6
DITCH 2	GS	Glyphosate	58	53	0.75	1.5	1.9	12
DITCH 3	GS	Glyphosate	56	48	<0.50	1.2	2.4	18
DITCH 5	GS	Glyphosate	66	38	<0.50	1.2	2.0	12
RESERVOIR	GS	Glyphosate	53	42	<0.50	0.53	0.17	1.6
DITCH 2	OS	Glyphosate	16	6.3	<0.50	0.87	0.63	2.5
DITCH 3	OS	Glyphosate	17	12	<0.50	0.73	0.70	3.4
DITCH 5	OS	Glyphosate	19	0	<0.50	6.2	21.6	95
RESERVOIR	OS	Glyphosate	36	0	<0.50	<0.50	0	<0.50
DITCH 2	ALL	Metolachlor	73	29	<2.0	3.3	3.8	22
DITCH 3	ALL	Metolachlor	71	24	<2.0	3.5	5.3	40
DITCH 5	ALL	Metolachlor	82	17	<2.0	2.6	2.3	17
RESERVOIR	ALL	Metolachlor	85	18	<2.0	2.1	0.38	4.1
DITCH 2	GS	Metolachlor	57	37	<2.0	3.6	4.2	22
DITCH 3	GS	Metolachlor	55	31	<2.0	3.9	5.9	40
DITCH 5	GS	Metolachlor	63	21	<2.0	2.8	2.6	17
RESERVOIR	GS	Metolachlor	50	28	<2.0	2.2	0.5	4.1
DITCH 2	OS	Metolachlor	16	0	<2.0	<2.0	0	<2.0
DITCH 3	OS	Metolachlor	16	0	<2.0	<2.0	0	<2.0
DITCH 5	OS	Metolachlor	19	5.3	<2.0	2.0	0.02	2.1
RESERVOIR	OS	Metolachlor	35	2.9	<2.0	2.0	0.02	2.1
DITCH 2	ALL	Quinclorac	73	63	0.74	2.2	4.3	22
DITCH 3	ALL	Quinclorac	71	76	0.89	2.1	2.7	15
DITCH 5	ALL	Quinclorac	82	82	0.99	2.9	5.0	29
RESERVOIR	ALL	Quinclorac	85	95	0.96	1.1	0.55	3.1
DITCH 2	GS	Quinclorac	57	70	0.85	2.0	3.9	22
DITCH 3	GS	Quinclorac	55	82	1.0	2.5	2.9	15
DITCH 5	GS	Quinclorac	63	89	1.4	3.6	5.5	29
RESERVOIR	GS	Quinclorac	50	98	0.97	1.2	0.61	3.1
DITCH 2	OS	Quinclorac	16	38	0.40	2.7	5.5	20
DITCH 3	OS	Quinclorac	16	56	0.56	0.78	0.70	3.2
DITCH 5	OS	Quinclorac	19	58	0.42	0.67	0.53	2.2
RESERVOIR	OS	Quinclorac	35	91	0.96	1.1	0.46	2.2

[a] RL = Reporting limit.
[b] SD = Standard deviation.
[c] Max = Maximum.
[d] GS = Growing season.
[e] OS = Off season.

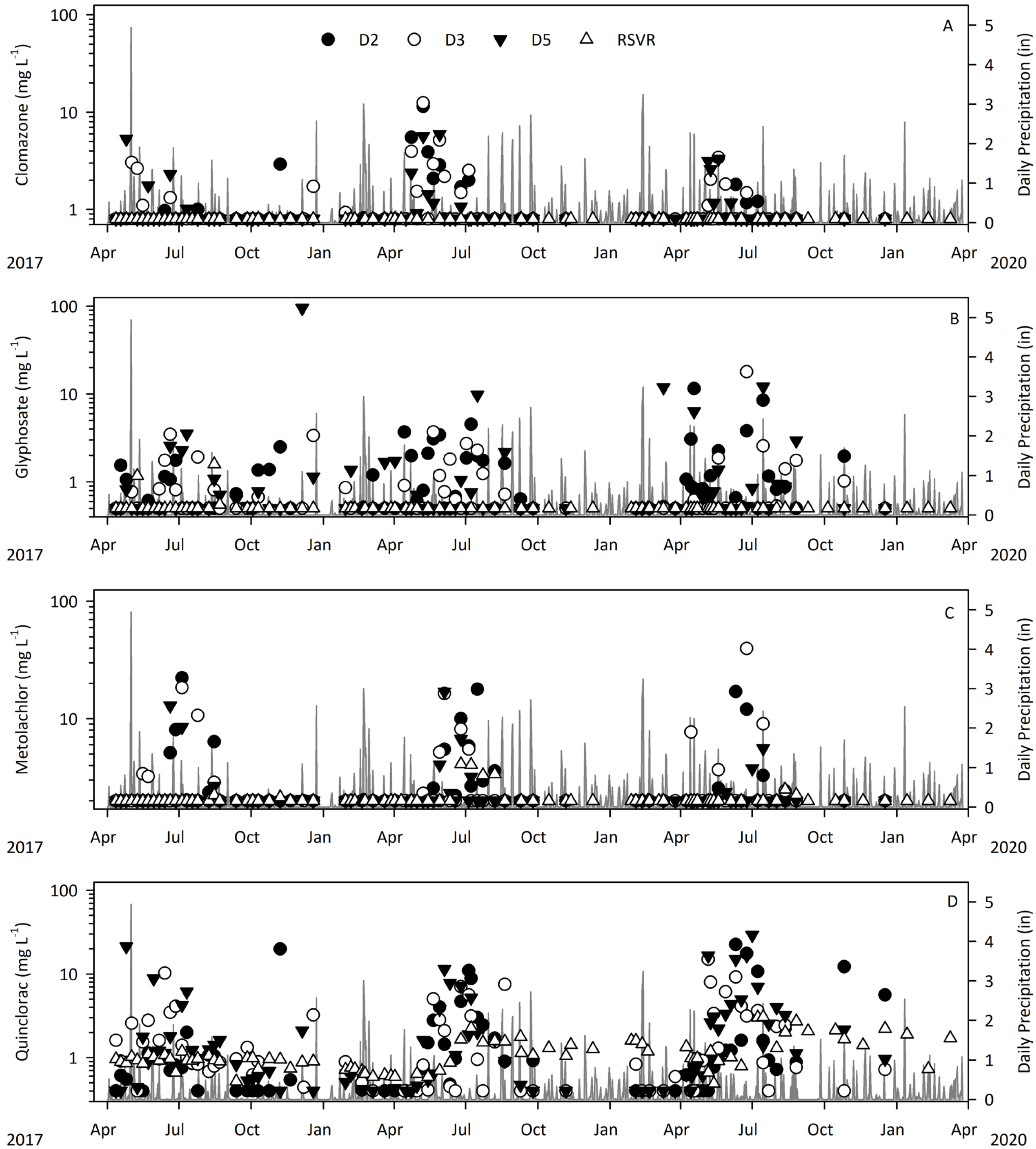

Fig. 2. Residual concentrations of A) clomazone, B) glyphosate, C) metolachlor, and D) quinclorac detected in the on-farm water storage-tailwater recovery system through time from April 2017–March 2020. D2 = Ditch 2, D3 = Ditch 3, D5 = Ditch 5, RSVR = Reservoir.

Evaluation of Weed Control with Multiple Cover Crop Termination Timings

Z.T. Hill,[1] *L.T. Barber,*[2] *T.R. Butts,*[2] *R.C. Doherty,*[1] *A. Ross,*[2] *and L.M. Collie*[2]

Abstract

Herbicide-resistant weeds, such as Palmer amaranth (*Amaranthus palmeri* S. Wats.), have become prevalent across the mid-south, resulting in a major economic impact on soybean yields. With the increasing loss of effective herbicides to control this weed, alternative methods are needed. An experiment was conducted in 2018 and 2019, at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station in Marianna, Ark., to evaluate the suppression of Palmer amaranth and to determine the best time to terminate cover crops for optimum weed control. In addition to a herbicide program, a cover crop blend was compared to cereal rye alone, conventional tillage, and a non-treated control to determine its effectiveness. Cover crop termination 2 weeks before planting (WBP), 1 WBP, and at planting; provided greater control of Palmer amaranth than the other treatments. Weed control evaluated 4 WAP, indicated most treatments provided greater than 90% control of Palmer amaranth, except for the 4 WBP termination timing. Soybean yields were comparable in all treatments except where the cover crop was not chemically terminated. These data suggest that incorporating cover crops in a soybean weed program is beneficial in controlling herbicide-resistant weeds; additionally, terminating the cover crops within two weeks of planting significantly increases weed control.

Introduction

Cover crops have become increasingly popular in the mid-south, primarily for the beneficial aspects of erosion control as well as an economic benefit to soil health and weed suppression (Creamer and Baldwin 2000; Price and Norsworthy 2013). In 2015 a regional study suggested that the use of cereal rye as a cover crop effectively suppressed Amaranthus species in soybean (Loux et al. 2017). With the increased interest in cultural methods for weed control, such as the utilization of cover crops, a common concern is when to terminate the cover crop to achieve optimum weed suppression throughout the growing season. This trial was designed to determine if differences in weed suppression existed based on when the cover crop was chemically terminated before planting.

Procedures

This study was conducted in 2018 and 2019 at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station in Marianna, Ark. to determine weed suppression in soybean based on cover crop termination. A common cover crop blend including cereal rye, Austrian winter pea, vetch, clover, and radish was planted and compared to straight cereal rye. Cover crops were planted in November of each year. A conventional tillage treatment was added for comparison, as well as a non-treated control treatment, where no herbicide was applied to terminate the cover crop. The test was designed as a randomized complete block with five cover crop termination timings: 4 weeks before planting (WBP), 3 WBP, 2 WBP, 1 WBP, and at planting (AP). Dicamba was applied at 22 oz/ac with glyphosate at 40 oz/ac for each termination timing. A postemergence application consisting of dicamba applied at 22 oz/ac plus a pre-mix of fomesafen + S-metolachlor at 32 oz/ac plus glyphosate at 32 oz/ac was made 14 days following crop emergence. Herbicide treatments were applied with a tractor-mounted sprayer calibrated to deliver 12 gallons per acre at 3 mph with TeeJet AIXR110015 nozzles. Asgrow variety 46X6 was planted on 9 May 2018 and 8 May 2019. Visual weed control assessments were observed at two and four weeks after planting for the control of Palmer amaranth (*Amaranthus palmeri* S. Wats.). Additionally, soybean was harvested and yields recorded both years.

Results and Discussion

The non-treated control treatments of both the cover crop blend and cereal rye were allowed to terminate and mature naturally. The 1 WBP and AP termination timings provided 91%–98% control of Palmer amaranth two weeks after crop emergence, which was not significantly different from

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the conventional tillage treatments (Table 1). The 4, 3, and 2 WBP termination timings only provided 78% control or less of Palmar amaranth due to the lack of biomass at the time of planting. Two weeks after the blanket POST application, another visual weed control assessment was taken. At this time, there was a significant difference between 4 WBP and most of the remaining treatments with 85% control in the cover crop blend and 74% control in the cereal rye at 4 WBP (Table 2). The 2, 1 WBP, and AP treatments achieved 95% control or better following the POST application. The plots that received no chemical termination (non-treated) resulted in significantly lower soybean yield, with no significant differences among all other treatments (Table 3).

Practical Applications

Regardless of the cover crop, these data suggest that the termination of the cover crop within two weeks before planting and at planting provided the greatest control of Palmer amaranth throughout the growing season. The incorporation of cover crops into an overall weed management program appears to be beneficial in controlling herbicide-resistant pigweed. Questions regarding termination still need to be answered, such as the potential negative benefits from troublesome insect populations if cover crops are terminated within the 4 weeks before planting.

Acknowledgments

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Price, A.J., and J.K. Norsworthy. 2013. Cover crops for weed management in southern reduced-tillage vegetable cropping systems. Weed Tech. 27:212-217.

Table 1. Palmer amaranth control 2 weeks after planting at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station, Marianna.

Termination Timing	No Cover Crop	Cover Crop Blend	Cereal Rye
	% Control		
Conventional Tillage	90		
4 WBP		32	32
3 WBP		67	55
2 WBP		76	78
1 WBP		92	92
At planting		93	91
Nontreated		83	91
LSD (*P* = 0.05) = 16.38			

Abbreviations: LSD = least significant difference; WBP = weeks before planting.

Table 2. Palmer amaranth control 2 weeks after the post-emergence (POST) application at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station, Marianna.

Termination Timing	No Cover Crop	Cover Crop Blend	Cereal Rye
	---------------% Control---------------		
Conventional Tillage	99		
4 WBP		85	74
3 WBP		95	90
2 WBP		98	95
1 WBP		98	98
At planting		96	98
Nontreated		97	98
LSD (*P* = 0.05) = 11.63			

Abbreviations: LSD = least significant difference; WBP = weeks before planting.

Table 3. Soybean yield as influenced by cover crop termination at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station, Marianna.

Termination Timing	No Cover Crop	Cover Crop Blend	Cereal Rye
	---------------bu./ac---------------		
Conventional Tillage	52		
4 WBP		51	54
3 WBP		55	55
2 WBP		53	56
1 WBP		48	51
At planting		52	56
Nontreated		43	48
LSD (*P* = 0.05) = 6.34			

Abbreviations: LSD = least significant difference; WBP = weeks before planting.

Control of Six-Way Resistant Palmer Amaranth in Soybean

Z.T. Hill,[1] L.T. Barber,[2] R.C, Doherty,[1] A. Ross,[2] L.M. Collie[2]

Abstract

In 2019, two experiments were conducted in Marion, Arkansas on a Dubbs silt loam soil to determine the effectiveness of Group 15 (chloroacetamide) herbicides on multiple site-of-action resistant Palmer amaranth (*Amaranthus palmeri* S. Wats.) when applied alone or in a herbicide program. In the first experiment, various rates of Dual Magnum®, Warrant®, Outlook®, and Zidua® were applied to determine the length of residual control each herbicide provided on a known metolachlor-resistant pigweed population. In the second experiment, multiple chloroacetamide's were included in various preemergence (PRE) herbicide combinations in an LLGT27 soybean technology system to determine the most effective program. In the first experiment, less than 90% control of Palmer amaranth was observed from most treatments at 2 weeks after planting (WAP). Dual Magnum applied at 16 oz/ac and Warrant at 48 oz/ac only provided 36% and 40% control, respectively, by 28 days after treatment (DAT). Throughout most of the season, Outlook at 12.8 and 16 oz/ac provided greater than 90% control of Palmer amaranth. In the second experiment, most herbicide programs provided greater than 90% control of Palmer amaranth at 2 WAP. The inclusion of Alite® 27 (isoxaflutole) with Zidua SC, Zidua PRO, Sonic®, and Boundary® applied PRE provided significantly greater control than the herbicides applied alone. By the end of the season, comparable yields were observed from most programs, with Zidua PRO + Alite 27 followed by Liberty™, providing the highest yield of 69 bu./ac. Overall, these data suggest that reduced control of Palmer amaranth was observed from most chloroacetamide herbicides, with Outlook being the only herbicide evaluated to provide effective control. Additionally, these data suggest that utilizing multiple herbicide sites of action at planting is necessary for season-long control of multiple-resistant Palmer amaranth.

Introduction

Over the past few decades, Palmer amaranth (*Amaranthus palmeri* S. Wats.) has been a continuously growing problem weed for Arkansas producers with the evolution of resistance to multiple herbicides from various sites of action. The most notable being to 5-enolpyruvyl shikimate-3-phosphate (EPSPS) inhibitors in 2006, protoporphyrinogen oxidase (PPO) inhibitors in 2016, and S-metolachlor a long-chain fatty acid inhibitor in 2017 (Heap, 2020). With the loss of these once effective herbicides, controlling this weed can be difficult without utilizing multiple effective sites-of-action, in addition to other best management practices (Schwartz-Lazaro et al., 2017). The first objective of these experiments was to determine if chloroacetamide herbicides continue to provide benefits in controlling this pigweed population and if differences in application rates exist. The second objective was to determine the fit of the LLGT27 soybean technology in programs with chloroacetamide herbicides.

Procedures

In 2019, two experiments were conducted in Marion, Arkansas, to determine the effectiveness of the chloroacetamide family of herbicides in controlling multiple site-of-action resistant Palmer amaranth in soybean [*Glycine max* (L.) Merr] as either a single application or incorporated into a herbicide program. Both experiments were conducted on a Dubbs silt loam soil in Marion, Ark. Both experiments were conducted as a randomized complete block design including four replications, with plot sizes of 12.6-ft by 30-ft planted on 30 April 2019 to Credenz variety CZ4539GTLL.

In the first experiment, multiple chloroacetamide herbicides were applied preemergence (PRE) at various rates to determine the length of residual of each herbicide in controlling Palmer amaranth. The PRE rates applied in this experiment included Dual Magnum® (S-metolachlor) at 16, 20.8, and 32 oz/ac, Outlook® (dimethenamid) at 12.8 and 16 oz/ac, Warrant® (acetochlor) at 32 and 48 oz/ac, and Zidua® SC (pyroxasulfone) at 2, 3.25, 4, and 5 oz/ac.

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In the second experiment, multiple chloroacetamide herbicides were applied PRE in various herbicide programs with and without Alite® 27 to determine the most effective herbicide program in controlling metolachlor-resistant Palmer amaranth. The programs included: Zidua SC at 2.5 oz/ac, Zidua® PRO (saflufenacil + imazethapyr + pyroxasulfone) at 4.5 oz/ac, Sonic® (sulfentrazone + cloransulam-methyl) at 5 oz/ac, and Boundary® (metribuzin + S-metolachlor) at 24 oz/ac applied PRE either alone or in combination with Alite 27 (isoxaflutole) at 2 oz/ac All PRE applications were followed by (fb) Liberty™ (glufosinate) at 32 oz/ac applied mid post-emergence (MPOST) 4 WAP.

For both experiments, PRE treatments were applied on 30 April 2019 with a Mudmaster mounted sprayer calibrated to deliver 12 gallons per acre at 3 miles per hour with Teejet AIXR110015 nozzles. Herbicide efficacy was evaluated at two and four weeks after planting (WAP). Additionally, herbicide efficacy was evaluated 2 weeks after the MPOST application, and crop yields were taken in the second experiment.

Results and Discussion

In the first experiment, most herbicide treatments provided less than 90% control of Palmer amaranth at 2 WAP (Table 1). Dual Magnum at 16 oz/ac and Warrant at 32 oz/ac provided the least amount of control 2 WAP at 63% and 43%, respectively. There was a significant rate response observed where Dual Magnum applied at 32 oz/ac increased control to 79% and 48 oz/ac. Warrant increased control to 60% 2 WAP. A rate response was also observed with Zidua, where control was only 69% 2 WAP at 2.0 oz/ac and was increased to 86% with 3.5 oz/ac. Regardless of the rate applied, both rates of Outlook provided greater than or equal to 95% control at the initial evaluation. Herbicide efficacy had diminished by 4 WAP applications, with most treatments providing less than 80% control of Palmer amaranth (Table 1). By this later evaluation, both rates of Outlook continued to provide effective control of Palmer amaranth.

In the second experiment, most programs provided greater than 90% control of Palmer amaranth at 2 WAP (Table 2). Zidua SC at 2.5 oz/ac and Sonic at 5 oz/ac applied alone failed to provide greater than 60% control of Palmer amaranth at 2 WAP. The inclusion of Alite 27 with Zidua SC, Zidua PRO, Boundary, increased control of Palmer amaranth to 99% 2 WAP compared to each herbicide applied alone (Table 2). By 4 WAP, herbicide efficacy had decreased in most treatments; albeit, Zidua SC + Alite 27, Zidua PRO alone, and Zidua PRO + Alite 27 continued to provide greater than 80% control of Palmer amaranth, with 89%, 82%, and 95% control, respectively (Table 2). At 14 days after the MPOST application, Zidua PRO at 4.5 oz/ac + Alite 27 at 2 oz/ac followed by Liberty at 32 oz/ac provided 95% control of Palmer amaranth (Table 3). By the end of the season, soybean yields were comparable across most programs with yields ranging from 53–69 bu./ac (Table 4). The herbicide program consisting of Zidua PRO + Alite 27 followed by Liberty yielded the highest with 69 bu./ac (Table 4).

Practical Applications

Based on these data, the use of chloroacetamide's on controlling multiple site-of-action resistant Palmer amaranth is not as effective as it had been in recent years, which can be problematic due to the lack of new herbicides being developed. Results indicate that the rate at which these herbicides are applied plays a big role in efficacy, especially 2 weeks following application. Out of all Group 15 herbicides, Outlook provided the best control regardless of rate; however, none of these should be applied alone at planting for control of multiple-resistant Palmer amaranth. Weed control programs using Alite 27 herbicide in combination with other PREs such as Boundary and Zidua SC etc. can be effective in reducing pigweed emergence and providing long residual control of multiple-resistant populations. An effective POST herbicide such as Liberty will still be required because pigweed emergence will occur before to crop canopy closure.

Acknowledgments

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Table 1. Palmer amaranth control at 2 and 4 weeks after planting in the length of the residual experiment at Marion, Arkansas.

Treatment	Rate	Application Timing	2 WAP	4 WAP
	oz/ac		--------------------% Control--------------------	
Dual Magnum	16.0	PRE	63	36
Dual Magnum	20.8	PRE	66	58
Dual Magnum	32.0	PRE	79	67
Warrant	32.0	PRE	43	5
Warrant	48.0	PRE	60	40
Outlook	12.8	PRE	95	88
Outlook	16.0	PRE	98	93
Zidua	2.0	PRE	69	57
Zidua	3.5	PRE	86	77
Zidua	4.0	PRE	83	74
Zidua	5.0	PRE	89	78
LSD (P = 0.05)			13.0	

Abbreviations: LSD = least significant difference; PRE = preemergence; WAP = weeks after planting.

Table 2. Palmer amaranth control at 2 and 4 weeks after planting in the programs experiment at Marion, Arkansas.

Treatment	Rate	Application Timing	2 WAP	4 WAP
	oz/ac		--------------------% Control--------------------	
Zidua SC	2.5	PRE	55	38
Zidua SC + Alite 27	2.5 + 2.0	PRE	99	89
Zidua PRO	4.5	PRE	94	82
Zidua PRO + Alite 27	4.5 + 2.0	PRE	99	95
Sonic	5.0	PRE	58	38
Sonic + Alite 27	5.0 + 2.0	PRE	84	53
Boundary	24.0	PRE	93	55
Boundary + Alite 27	24.0 + 2.0	PRE	99	72
LSD (P = 0.05)			7.0	11.2

Abbreviations: LSD = least significant difference; PRE = preemergence; WAP = weeks after planting.

Table 3. Palmer amaranth control at 2 weeks after the mid-postemergence application in the programs experiment at Marion, Arkansas.

Treatment	Rate	Application Timing	2 WAMPOST
	oz/ac		---------% Control---------
Zidua SC	2.5	PRE	40
Zidua SC + Alite 27 fb Liberty	2.5 + 2.0 fb 32.0	PRE fb MPOST	86
Zidua PRO	4.5	PRE	69
Zidua PRO + Alite 27 fb Liberty	4.5 + 2.0 fb 32.0	PRE fb MPOST	95
Sonic	5.0	PRE	47
Sonic + Alite 27 fb Liberty	5.0 + 2.0 fb 32.0	PRE fb MPOST	50
Boundary	24.0	PRE	55
Boundary + Alite 27 fb Liberty	24.0 + 2.0 fb 32.0	PRE fb MPOST	83
LSD (P = 0.05)			15.7

Abbreviations: fb = followed by; LSD = least significant difference; PRE = preemergence; MPOST = mid-postemergence; WAMPOST = weeks after the MPOST application.

Table 4. Soybean yield in the programs experiment at Marion, Arkansas.

Treatment	Rate	Application Timing	Yield
	oz/ac		**---------bu./ac---------**
Zidua SC	2.5	PRE	58
Zidua SC + Alite 27 fb Liberty	2.5 + 2.0 fb 32.0	PRE fb MPOST	58
Zidua PRO	4.5	PRE	61
Zidua PRO + Alite 27 fb Liberty	4.5 + 2.0 fb 32.0	PRE fb MPOST	69
Sonic	5.0	PRE	53
Sonic + Alite 27 fb Liberty	5.0 + 2.0 fb 32.0	PRE fb MPOST	57
Boundary	24.0	PRE	61
Boundary + Alite 27 fb Liberty	24.0 + 2.0 fb 32.0	PRE fb MPOST	66
LSD (P=0.05)			11.6

Abbreviations: fb = followed by; LSD = least significant difference; PRE = preemergence;
MPOST = mid-postemergence.

Prickly sida and Grass Species Control in Xtend™ and Enlist® Soybean Systems

Z.T. Hill,[1] L.T. Barber,[2] R.C. Doherty,[1] L.M. Collie,[2] and A. Ross[2]

Abstract

In 2019, two experiments were conducted in Tillar, Ark., on a silt loam soil to determine the most effective programs in controlling prickly sida (*Sida spinosa* L.) and barnyardgrass (*Echinochloa crus-galli* (L) P. Beauv.) in Enlist™ and Xtend® soybean systems. In the Enlist experiment, Trivence® was applied preemergence (PRE) in all treatments followed by multiple postemergence (POST) herbicides. In the Xtend experiment, multiple PRE herbicides were applied, followed by Roundup® Powermax + Xtendimax®. Herbicide efficacy was evaluated in both experiments at varying times throughout the 2019 growing season. In the Enlist experiment, most herbicide programs provided greater than 85% control of barnyardgrass and prickly sida throughout the season, with Trivence fb Enlist + Liberty™ + EverpreX® providing the greatest control. In the Xtend experiment, herbicide programs containing a PRE and POST herbicide provided effective control of these weeds throughout the season, whereas the POST-only program was ineffective. Overall, these data suggest that the use of these technologies can be effective in controlling these problematic weeds. Additionally, the use of both residual (PRE) and POST herbicides is necessary to provide an adequate level of control.

Introduction

With the continued spread and further development of herbicide resistance observed in Palmer amaranth (*Amaranthus palmeri* S. Wats.) (Heap, 2020), the need for new herbicide technologies is required. In recent years, the utilization of the synthetic auxin technologies Enlist™ and Xtend® have proven to provide effective control of herbicide-resistant Palmer amaranth and other problematic weeds in Arkansas soybean (Meyer and Norsworthy, 2019). The increase in adoption of Xtend technology and, therefore, applications of approved dicamba formulations have increased prickly sida (*Sida spinosa* L.) occurrence in fields following applications (Tom Barber, personal communication). Palmer amaranth has generally been the driving factor in the adoption of these new herbicide technologies, but it was unknown whether or not an increase in auxin applications could potentially cause weed shifts or increases in other difficult to control species such as prickly sida and barnyardgrass (*Echinochloa crus-galli* (L) P. Beauv.). The objective of this experiment was to determine what additional programs, if any, would be needed in controlling prickly sida and barnyardgrass in Enlist and Xtend soybean technologies.

Procedures

Two experiments were conducted at Tillar, Ark. in 2019, to determine the most effective programs for controlling prickly sida and barnyardgrass in an Enlist and Xtend herbicide system. Both experiments were conducted on a silt loam soil in Tillar, Arkansas, with a texture of 18% sand, 56% silt, and 26% clay. Additionally, both experiments were set up as a randomized complete block design with four replications. Plot sizes were 12.66-ft by 30-ft and were planted on 1 July 2019 to Enlist variety (XBP51010E) and Xtend variety (AG46X6).

In the Enlist experiment, Trivence® (chlorimuron, flumioxazin, and metribuzin) was applied at 8 oz/ac. A preemergence (PRE) in all treatments followed by (fb) multiple combinations of postemergence (POST) herbicides. POST treatments (29 days after PRE) included in this experiment are Durango® DMA® (glyphosate) at 32 oz/ac, Enlist® Duo (2,4-D choline + glyphosate) at 56 oz/ac, Enlist Duo at 75 oz/ac, Enlist One (2,4-D choline) at 32 oz/ac plus Liberty™ (glufosinate) at 29 oz/ac, Liberty at 29 oz/ac, and Enlist One at 32 oz/ac plus Liberty at 29 oz/ac plus EverpreX® (S-metolachlor) at 16 oz/ac.

In the Xtend experiment, multiple PRE herbicides were applied fb Roundup Powermax (glyphosate) at 32 oz/ac plus Xtendimax (dicamba) at 22 oz/ac applied early POST (V2) or late POST (21 days after PRE) in most systems, as well as one system that contained Scout (glufosinate) at 32 oz/ac applied late POST. PRE herbicides included in this experiment were Fierce® EZ at 6 oz/ac, Fierce® MTZ at 16 oz/ac, Valor® SX at 1.96 oz/ac plus Tricor® 4F at 6 oz/ac plus Prowl® H_2O at 24 oz/ac, and Boundary® at 32 oz/ac.

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Herbicide treatments were applied with a tractor-mounted sprayer calibrated to deliver 12 gallons per acre at 3 mph with TeeJet AIXR110015 nozzles for non-synthetic auxin treatments and TeeJet TTI110015 nozzles for synthetic auxin treatments. Herbicide efficacy was evaluated in both experiments at varying times throughout the 2019 growing season.

Results and Discussion

In the Enlist experiment, most of the herbicide systems provided greater than 85% control of prickly sida and barnyardgrass 21 days after the POST (DAPOST) application (Table 1). The Enlist system containing Enlist One (2,4-D choline), Liberty (glufosinate), and EverpreX (S-metolachlor) applied POST provided the greatest control of prickly sida and barnyardgrass at the same timing, with 99% and 96% control, respectively (Table 1). By 29 DAPOST, most of the systems provided greater control of both species than previously observed, with most treatments providing ≥ 90% control (Table 2).

In the Xtend experiment, the herbicide systems containing a residual herbicide applied PRE provided greater control of both species at 10 days after the early POST (EPOST) application than the POST-only system, which only provided 83% control of prickly sida and 68% control of barnyardgrass (Table 3). It was also observed that among PRE treatments, Fierce EZ and the three-way combination of Valor, Tricor, and Prowl PRE provided the lowest control of barnyardgrass at 86% and 82%, respectively. By 13 DAPOST application, the control of both species increased to 99% in the systems that contained both a PRE and POST application; whereas, control from the POST-only system remained ineffective (Table 4).

Practical Applications

Based on these data, the use of Enlist and Xtend technologies can be effective in controlling prickly sida and barnyardgrass, which can be problematic weeds in Arkansas soybean. Regardless of the technology, season-long effective control of both prickly sida and barnyardgrass will require a diverse system of PRE residuals applied at planting followed by timely POST applications, generally around 21 days after planting. Residual herbicides will continue to be necessary for adequate control of these weed species, in addition to reducing the spread of herbicide-resistant weeds such as pigweed. Growers who attempt to utilize new auxin technologies without residuals at planting will likely run into issues with not only pigweed but also prickly sida and barnyardgrass.

Acknowledgments

The authors would like to thank the Arkansas Soybean Promotion Board and the University of Arkansas System Division of Agriculture for their support and funding for this project.

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Table 1. Prickly sida and barnyardgrass control at 21 days after the postemergence (POST) application in Enlist™ soybean at Tillar, Arkansas.

Program[a]	Rate	Application timing	Prickly sida	Barnyardgrass
	oz/ac		-------------------% Control	----------------------
Durango® DMA®	32	POST	87	83
Enlist Duo®	56	POST	79	81
Enlist Duo	76	POST	86	89
Enlist® + Liberty™	32 + 29	POST	89	85
Liberty	29	POST	87	87
Enlist + Liberty + EverpreX®	32 + 29 + 16	POST	99	96
LSD (*P* = 0.05)			13.41	10.49

[a]All treatments contained Trivence® at 8 oz/ac applied preemergence. Abbreviations: LSD = least significant difference.

Table 2. Prickly sida and barnyardgrass control at 29 days after the postemergence (POST) application in Enlist™ soybean at Tillar, Arkansas.

Program[a]	Rate	Application timing	Prickly sida	Barnyardgrass
	oz/ac		------------------% Control--------------------	
Durango® DMA®	32	POST	91	87
Enlist Duo®	56	POST	91	91
Enlist Duo	76	POST	95	91
Enlist® + Liberty™	32 + 29	POST	88	93
Liberty	29	POST	90	81
Enlist + Liberty + EverpreX®	32 + 29 + 16	POST	98	96
LSD (*P* = 0.05)			12.69	7.42

[a]All treatments contained Trivence® at 8 oz/ac applied preemergence. Abbreviations: LSD = least significant difference.

Table 3. Prickly sida and barnyardgrass control at 10 days after the early postemergence (EPOST)[a] application in Xtend® soybean at Tillar, Arkansas.

Program	Rate	Application timing	Prickly sida	Barnyardgrass
	oz/ac		------------------% Control-----------------	
Rup Pmax +Xtendimax®[b]	32 + 22	EPOST	83	68
Fierce® EZ	6	PRE	99	86
Fierce® MTZ	16	PRE	99	97
Valor® SX + Tricor 4F + Prowl® H_20	1.96 + 6 + 24	PRE	95	82
Fierce® MTZ	16	PRE	99	95
Boundary®	32	PRE	97	94
LSD (*P* = 0.05)			4.36	7.45

[a]Early postemergence applied at V2.

[b]Treatment 1 included Induce® at 3.84 oz/ac + Intact® at 7.7 oz/ac applied EPOST. Abbreviations: fb = followed by; LSD = least significant difference; EPOST = early postemergence; PRE = preemergence; Rup Pmax = Roundup Powermax®.

Table 4. Prickly sida and barnyardgrass control at 13 days after the postemergence (POST)[a] application in Xtend® soybean at Tillar, Arkansas.

Program	Rate	Application timing	Prickly sida	Barnyardgrass
	oz/ac		-------------% Control--------------	
Rup Pmax +Xtendimax®[b]	32 + 22	EPOST	65	86
Fierce® EZ fb Rup Pmax + Xtendimax	6 fb 32 + 22	PRE fb POST	99	99
Fierce MTZ fb Rup Pmax + Xtendimax	16 fb 32 + 22	PRE fb POST	99	99
Valor® SX + Tricor 4F + Prowl® H_20 fb Rup Pmax + Xtendimax	1.96 + 6 + 24 fb 32 + 22	PRE fb POST	99	99
Fierce MTZ fb Scout®	16 fb 32	PRE fb POST	99	99
Boundary® fb Rup + Xtendimax	32 fb 32 + 22	PRE fb POST	99	99
LSD (*P* = 0.05)			7.55	9.73

[a] Postemergence applications applied 21 days following planting.

[b] Treatments 1–4 included Induce® at 3.84 oz/ac + Intact at 7.7 oz/ac applied POST; treatment 5 included AMS at 40 oz/ac applied POST. Abbreviations: fb = followed by; LSD = least significant difference; oz = ounces; EPOST = early postemergence; PRE = preemergence; POST = postemergence; Rup Pmax = Roundup Powermax®.

Optimizing the Use of Dicamba and Glufosinate in the XtendFlex™ System

G.L. Priess,[1] J.K. Norsworthy,[2] R.B. Farr,[1] and M.C. Castner[1]

Abstract

Dicamba formulations like Engenia®, Fexapan®, and Xtendimax® with VaporGrip® are being considered for labeling over-the-top of the upcoming XtendFlex™ soybean technology; however, it is unlikely that dicamba and glufosinate will be applied in the mixture based on current labels in XtendFlex™ cotton. In 2019, field experiments were conducted in Crawfordsville, Marianna, and Keiser, Ark., to evaluate the efficacy of dicamba followed by glufosinate and glufosinate followed by dicamba when applied at 0.2 (6 hours), 3, 7, 14, and 21-day intervals from the initial application on native Palmer amaranth (*Amaranthus palmeri* S. Wats.) populations. Field experiments were conducted to evaluate if the time interval between sequential applications could be optimized to improve Palmer amaranth control when compared to currently used dicamba and glufosinate postemergence (POST) herbicide systems. In two of the three experiments where Palmer amaranth weed size was greater than 5 in. at the initial application, dicamba followed by glufosinate at the 14-day interval provided consistently greater control than either sequence of dicamba and glufosinate at 0.2, 3, and 7-day intervals. Overall, dicamba followed by glufosinate at the 14-day interval provided equal or greater control than dicamba followed by dicamba or glufosinate followed by glufosinate at any interval. The addition of two effective herbicide sites-of-action for POST control of Palmer amaranth will mitigate the evolution of target-site herbicide resistance and aid in the preservation of the upcoming XtendFlex™ soybean technology.

Introduction

The commercial launch of XtendFlex™ soybean, resistant to dicamba, glufosinate, and glyphosate, enables producers to use these herbicides in season. Current soybean technologies like Xtend™ or LibertyLink™ rely on a single site-of-action (SOA) postemergence (POST) to control Palmer amaranth (Amaranthus palmeri S. Wats.) with resistance to acetolactate synthase (ALS), 5-enolpyruvyl shikimate-3-phosphate synthase (EPSPS), and protoporphyrinogen oxidase (PPO) inhibiting herbicides (Heap, 2020). In the past, over-reliance on an SOA perpetuated the evolution of herbicide resistance (Norsworthy et al., 2012). Now producers will have the option to plant XtendFlex™ soybean, thus allowing for separate applications of two effective SOA. Prior research has shown that utilizing two effective SOA in mixture or rotation will reduce the likelihood of the evolution of target-site herbicide resistance (Norsworthy et al., 2012). However, when combining herbicides with different SOA into a herbicide program, interactions can be nonexistent, favorable, or unfavorable. Some interactions between dicamba and glufosinate have been evaluated, such as glufosinate in mixture with dicamba (Chahal and Johnson, 2012; Vann et al., 2017). The results in the literature mentioned above were variable and exclusive to individual weed species. However, the label restrictions in cotton prohibit the mixture of dicamba and glufosinate (Anonymous, 2018). Therefore, additional research is needed to understand how to optimize the efficacy of dicamba and glufosinate when applied sequentially for the upcoming XtendFlex soybean technology.

Procedures

Field experiments were conducted in 2019, in Keiser Ark., near Crawfordsville, Ark., and near Marianna, Ark. Treatments applied in the experiments are shown in Table 1. Treatments were applied to native Palmer amaranth populations at each location without a crop present. Plot size at all locations was 3.16-ft wide and 20-ft long with four replications. Applications of each herbicide were made with separate hand-held CO_2-pressurized backpack sprayers to avoid any herbicide contamination. The hand-held sprayers were calibrated to deliver 15 gallons per acre of spray solution at 3 mph. All dicamba applications were made with TTI 110015-VP (TeeJet, Spring-

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field, Ill.) nozzles to attempt to abide by the label requirement of an ultra-coarse droplet size (Anonymous, 2018). Glufosinate applications were made with an AIXR 110015-VP (TeeJet, Springfield, Ill.) to attempt to maximize glufosinate efficacy while minimizing drift across plots. The mixture of dicamba + glufosinate was made with TTI 110015-VP nozzles. Before the first herbicide applications, either dimethenamid-P (Outlook®) or S-metolachlor (Dual®) was applied to reduce Palmer amaranth emergence. Subsequent applications of dimethenamid-P or S-metolachlor were made on a biweekly interval until all assessments were finished. Palmer amaranth control was evaluated 28 days after the final application in each treatment through visual assessments.

Data were subjected to an analysis of variance in JMP 14.1 (SAS Institute. Inc., Cary, N.C.) and site years were analyzed separately due to varying weed size at each location (Crawfordsville, 3-in. tall Palmer amaranth, Keiser, 7-in. tall Palmer amaranth, Marianna, 8-in. tall Palmer amaranth). Means were separated using Fisher's least significant difference test where $\alpha = 0.05$.

Results and Discussion

Dicamba and glufosinate can both be incorporated into a POST herbicide program effectively if the sequence of the two herbicides and timing between the applications is optimized. Palmer amaranth control ranged from 41%–71% (data not shown) when glufosinate was applied 4 hours before dicamba; thus this treatment is not a viable option for Palmer amaranth control. In general, when glufosinate was applied before dicamba, the efficacy of Palmer amaranth was than dicamba or glufosinate POST herbicide systems alone. Overall, when the time interval between sequential applications of dicamba and glufosinate was increased to 14 days, Palmer amaranth efficacy was generally optimized (Figs. 1–3). The sequential application of dicamba followed by glufosinate 14 days later provided equal or greater control than the dicamba or glufosinate system alone and provided greater control than glufosinate followed by dicamba at all time intervals.

Practical Applications

Dicamba and glufosinate should not be applied in sequence of one another in periods shorter than 14 days. In order to increase Palmer amaranth efficacy and utilize two effective SOA, dicamba should be applied 14 days before a glufosinate application. Also, only when dicamba followed by glufosinate at the 14-day interval was applied to 3-in. tall Palmer amaranth was 100% control observed. It is of the utmost importance to continue to apply effective POST herbicides to labeled weed sizes in the XtendFlex™ system as well as using the herbicide sequence and timing recommendations.

Acknowledgments

The authors would like to thank the Arkansas Soybean Promotion Board and Bayer CropScience for funding the research and the University of Arkansas System Division of Agriculture for their support.

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Table 1. Experimental treatments, including herbicides, herbicide rate, and the time interval between the sequential herbicide applications are displayed below.

Herbicide	Rate	Time interval between sequential applications
	oz/ac	
Non-treated	-	-
Dicamba[a]	22	-
Glufosinate[b]	32	-
Dicamba + glufosinate	22 + 32	-
Dicamba fb dicamba	32 fb 22	7, 14, and 21 days
Glufosinate fb glufosinate	32 fb 32	7, 14, and 21 days
Dicamba fb glufosinate	22 fb 32	6 hours, 3, 7, 14, and 21 days
Glufosinate fb dicamba	32 fb 22	6 hours, 3, 7, 14, and 21 days

fb = followed by.

[a] The dicamba formulation used was Xtendimax® plus VaporGrip®.

[b] The glufosinate formulation used was Liberty™.

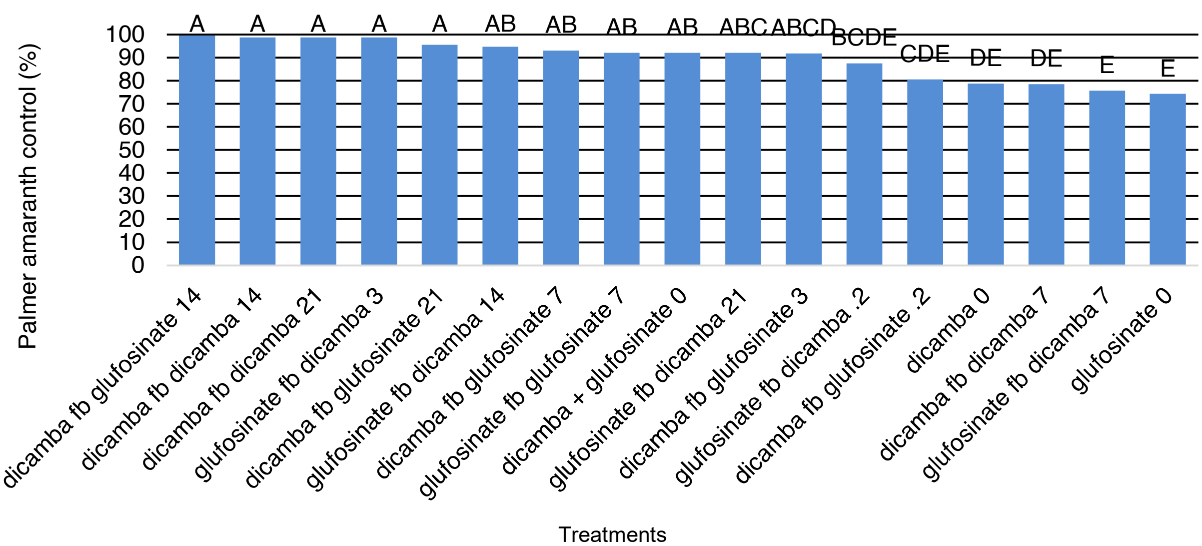

Fig. 1. Visible estimations of control of 3-inch tall Palmer amaranth provided by treatments at Crawfordsville, Arkansas, in 2019. The treatments are listed by herbicide A followed by herbicide B. The subsequent number represents the time interval in days between sequential applications.

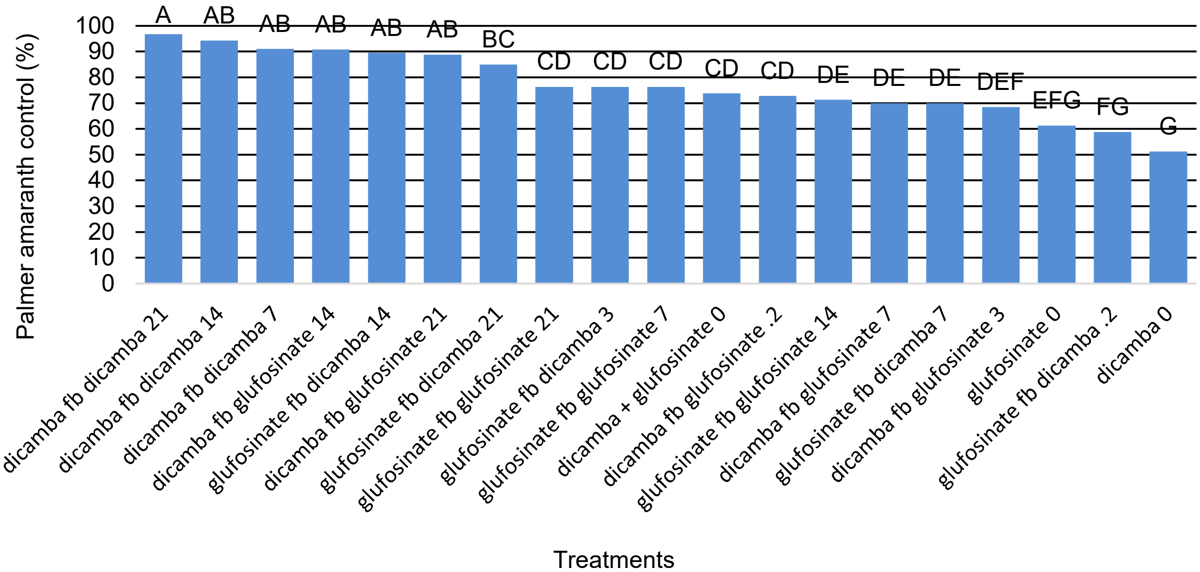

Fig. 2. Visible estimations of control of 7-inch tall Palmer amaranth provided by treatments at Keiser, Arkansas, in 2019. The treatments are listed by herbicide A followed by herbicide B. The subsequent number represents the time interval in days between sequential applications.

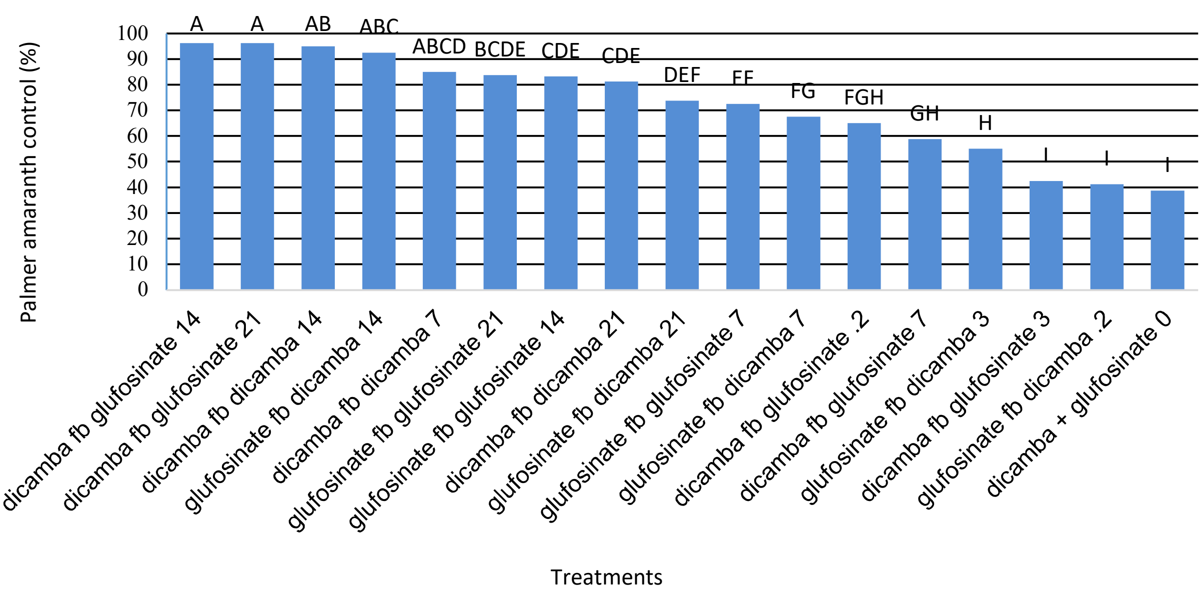

Fig. 3. Visible estimations of control of 8-inch tall Palmer amaranth provided by treatments, at Marianna, Arkansas, 2019. The treatments are listed by herbicide A followed by herbicide B. The subsequent number represents the time interval in days between sequential applications.

Weed Control Programs for Xtend® Soybean in Arkansas

M.L. Zaccaro,[1] J.K. Norsworthy,[1] R.B. Farr,[1] and T. Barber[2]

Abstract

A field experiment was conducted in 2019 to evaluate weed control options comparing herbicide programs that involved preemergence and postemergence applications to control a broad-spectrum of weed species in Xtend® soybean. The herbicide programs tested included Tavium® plus VaporGrip®, Boundary®, Broadaxe®, Prefix®, Roundup® PowerMax®, Valor® XLT, Zidua® Pro, Engenia® and XtendiMax® with VaporGrip®. Palmer amaranth (*Amaranthus palmeri* S. Wats.) and barnyardgrass [*Echinochloa crus-galli* (L.) P. Beauv.] control was estimated at 14 and 28 days after postemergence application (DA POST), and soybean yield was collected at maturity. Palmer amaranth control was greater than 90% for all herbicide treatments, except for flumioxazin plus chlorimuron followed by dicamba plus glyphosate that achieved 88% at 14 DA POST. However, at 28 DA POST, there were no significant differences in Palmer amaranth control among treatments, which averaged 98%. With respect to barnyardgrass control, all herbicide programs provided high barnyardgrass control (99%–100%) at 14 DA POST, while flumioxazin plus chlorimuron followed by dicamba plus glyphosate achieved 91% control. By 28 DA POST, barnyardgrass control was 100% in all treatments. Herbicide programs were not different for soybean yield, which averaged 53 bu./ac. Overall, all herbicide programs tested resulted in high weed control during the season and no significant impact on the soybean crop.

Introduction

According to surveys, Palmer amaranth (*Amaranthus palmeri* S. Wats.), morningglories (*Ipomoea* spp.), barnyardgrass [*Echinochloa crus-galli* (L.) P. Beauv.] and horseweed (*Erigeron canadensis* L.) have been the most problematic weeds for soybean production in the mid-south (Riar et al., 2013). No new herbicide site-of-action has been introduced to the market in the past 20 years (Duke, 2012). Consequently, reports of herbicide-resistant weeds continue to grow, putting our production systems in great pressure. Currently, in the region, reports of weed resistance continue to occur, including resistance to 5-enolpyruvylshikimate-3-phosphate synthase (EPSPS) (group 9), protoporphyrinogen oxygenase (PPO) (group 14), and most recently, to very-long-chain-fatty-acid (VLCFA) inhibitors (group 15) (Heap, 2020).

There is a necessity to research the utilization of the existing herbicides to determine the best management programs that confer wide-spectrum control. Recently, the release of the Xtend® technology in soybean allowed the application of dicamba and glyphosate postemergence in the crop, a potential tool for providing high efficacy of glyphosate-resistant weeds (Underwood et al., 2017). Following this development, other herbicides were released, focusing on the new Xtend market. For instance, Tavium® plus VaporGrip® was first commercialized in 2019 and combined the residual activity of S-metolachlor (group 15) with the broadleaf control efficacy of dicamba (group 4) (Anonymous, 2019). But, no single herbicide application can provide adequate control, and a systematic combination of herbicides and application timings are essential to successfully manage weeds during the entire growing season (Barber et al., 2020). The objective of this research was to evaluate herbicide weed control options that included preemergence and postemergence options to control a broad-spectrum of weed species in Xtend soybean, without negatively impacting the crop.

Procedures

A field study was conducted in 2019, near Crawfordsville, Ark., on a Forestdale silty clay loam soil. Xtend soybean (AG 46X6) was planted on 29 May 2019, at a seeding rate of 145,000 seeds/ac on 38-in. row spacing. Plot size was 12.7 × 20 ft, and the experiment was set up as a randomized complete block design with 6 treatments (herbicide programs) and 4 replications.

Herbicide treatments were applied using a CO_2-pressurized backpack sprayer equipped with a 6-nozzle boom and

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TTI 110015 nozzles, calibrated to deliver a constant carrier volume of 15 gal/ac. The herbicide programs evaluated included dicamba, *S*-metolachlor, glyphosate, metribuzin, fomesafen, flumioxazin, sulfentrazone, chlorimuron-ethyl, saflufenacil, imazethapyr, and pyroxasulfone. The herbicide treatment programs, rates, application timings, and the sites-of-action used in this research can be found in Table 1. The preemergence applications were made on the day of planting. The postemergence applications were made 26 days after planting when soybean was at the V4 growth stage, and Palmer amaranth plants were up to 2-in. tall. A non-treated control was included for reference. All plots were maintained according to the University of Arkansas System Division of Agriculture's Cooperative Extension Service recommendations.

Data collection included Palmer amaranth and barnyardgrass visible estimations of control and visible injury at 14 and 28 days after the postemergence application (DA POST). Soybean yield was harvested at maturity using a small-plot combine. Data were subjected to analysis of variance, and means were separated using Fisher's protected least significant difference test with $\alpha = 0.05$.

Results and Discussion

A high level of crop tolerance to the herbicide treatments was observed. Crop injury was not observed following herbicide treatments up to 14 DA POST. Low visible injury levels were observed only at 28 DA POST for two treatments tested. Treatments 3 and 5 elicited 2.5% and 5% injury to soybean plants, respectively (data not shown). This injury level is considered commercially acceptable. Previous research reported that transient injury could occur to soybean following the application of herbicides that include sulfentrazone and flumioxazin (Mahoney et al., 2014).

As expected, all herbicide programs provided significantly better weed control than the non-treated. Palmer amaranth control was greater than 90% for all herbicide treatments, except for treatment 5 that achieved 88% at 14 DA POST. However, at 28 DA POST, there were no significant differences in Palmer amaranth control, which averaged 98%. With respect to barnyardgrass control, most herbicide programs provided high barnyardgrass control (99%–100%) at 14 DA POST, while treatment 5 provided 91% control. By 28 DA POST, barnyardgrass control was 100% in all herbicide-treated plots (Table 2).

No significant differences were observed among the herbicide programs for soybean yield, which averaged 53 bu./ac. These herbicide treatments produced a higher yield than the non-treated control, which was only 30 bu./ac, a testament to weed density and competitiveness of Palmer amaranth and barnyardgrass in this trial (Table 2).

Practical Applications

Overall, all herbicide programs tested resulted in high weed control during the season, and no significant impact occurred to Xtend soybean. These programs contain several sites-of-action (Table 1), which provided a broad-spectrum of control. The application of these herbicide programs, with a wide range of sites-of-action, is more successful in reducing weed density and in contributing to the depletion of the soil seed-bank (Gallandt, 2006). A specific training before the purchase and use of dicamba herbicides (XtendiMax, Engenia, and Tavium) is required in the state of Arkansas. It is recommended to read each herbicide label before use and/or mixing herbicides.

Acknowledgments

We would like to express our appreciation for funding and support from the Syngenta Corporation and the Arkansas Soybean Research and Promotion Board, and the support provided by the University of Arkansas System Division of Agriculture.

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Table 1. Herbicide program treatments, application timings, rates, and the corresponding site-of-action groups evaluated in the Crawfordsville, Ark. experiment in 2019.†

Treatment	Preemergence	Postemergence‡	Site of action groups
1	Non-treated control		
2	Boundary®	Tavium® plus VaporGrip® + Roundup PowerMax®	4, 5, 9 and 15
3	Broadaxe® XC	Tavium® plus VaporGrip® + Roundup PowerMax®	4, 9, 14, and 15
4	Prefix®	Tavium® plus VaporGrip® + Roundup PowerMax®	4, 9, 14, and 15
5	Valor® XLT	XtendiMax® with VaporGrip® + Roundup PowerMax®	2, 4, 9, and 14
6	Zidua® Pro	Engenia® + Roundup PowerMax®	2, 4, 9, 14 and 15

† Boundary®, metribuzin and *S*-metolachlor, 2 pt/acre; Broadaxe® XC, *S*-metolachlor and sulfentrazone, 22 fl oz/acre; Tavium® plus VaporGrip®, dicamba and *S*-metolachlor, 56.5 fl oz/ac; Roundup PowerMax®, glyphosate, 32 fl oz/ac; Prefix®, *S*-metolachlor, and fomesafen, 32 fl oz/ac, Valor® XLT, flumioxazin and chlorimuron-ethyl, 3 oz/ac; XtendiMax® with VaporGrip®, dicamba, 22 fl oz/ac.; Engenia®, dicamba, 12.8 fl oz/ac; Zidua® Pro, saflufenacil, imazethapyr, and pyroxasulfone, 4.5 fl oz/ac.

‡ All postemergence treatments included Intact™ 0.5% v/v, and Class Act Ridion® 1% v/v.

Table 2. Palmer amaranth and barnyardgrass visible estimations of control at 14 and 28 days after postemergence application (DA POST), and soybean yield influenced by the treatments.†

Treatment	Palmer amaranth		barnyardgrass		Soybean
	14 DA POST	28 DA POST	14 DA POST	28 DA POST	Yield
	------------------------ % control (of non-treated) ------------------------				bu./ac
1	-	-	-	-	30.1 b
2	95 ab	96 a	100 a	100 a	56.6 a
3	99 a	100 a	100 a	100 a	50.1 a
4	99 a	98 a	99 a	100 a	56.1 a
5	88 b	98 a	91 b	98 a	52.1 a
6	97 a	99 a	99 a	99 a	52.3 a

†Means followed by the same letter, within a column, are not statistically different at α = 0.05, according to Fisher's protected least significant difference test.

Potential of Nitrogen and Potassium Fertilizer Application to Mitigate Yield Loss and Injury in Soybean Damaged by Off-Target Dicamba Movement

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Abstract

Discovery of a relationship between herbicide injury to crops and additional fertilization could provide means of mitigating yield loss and aid recovery of the crop. The objective of this study was to determine if fertilizer inputs following dicamba injury to soybean could aid recovery and reduce yield loss in soybean. The trial included a 1/150x rate of dicamba, and nitrogen (N) and potassium (K) fertilizers applied at 60 and 45 lb/ac, respectively, after dicamba exposure. Factors in the analysis were dicamba application timing to soybean (R1, R3, and R1 plus R3) and fertilizer type applied (N, K, N plus K). Statistical analysis revealed a significant interaction between factors for both injury ($P = 0.0273$) and biomass data ($P = 0.0169$), with slightly less injury among treatments receiving both N and K; however, biomass was reduced among treatments receiving both N and K when compared to treatments receiving no fertilizer. There was a significant main effect of application timing to relative yield ($P < 0.0001$) but no effect of fertilizer application ($P = 0.7198$). Treatments applied with dicamba at the R1 timing had the greatest relative yield (87% of the non-treated control) followed by the R3 timing (69%) with the sequentially applied treatment having the lowest relative yield (24%).

Introduction

The mid-southern agricultural region has unique characteristics allowing for high potential soybean yields, such as a wide planting window, which in turn allows for wide cultivar and maturity group (MG) selection (Salmeron et al., 2014). By understanding the interaction between adaptable factors that affect soybean growth and yield, such as the impact of additional fertilization on herbicide injury sustained by soybean, recovery may be augmented and yields safeguarded. A study focused on the influence of nitrogen (N) fertilization timings and its effect on how rice responds to herbicide applications representing multiple sites-of-action, showed that N applied to rice pre-flood favors crop recovery from an application of bentazon versus N applied post-flood, which delayed recovery from bentazon injury (Langaro et al., 2018). The opposite behavior was found in the case of bispyribac-sodium, which caused greater injury to rice when all N was applied pre-flood. Related specifically to soybean, laboratory studies conducted by Nizampatnam et al. (2015) found that auxin injury can reduce legume nodulation, decreasing N fixation. This may partially account for yield reduction due to auxin injury to soybean. A study conducted by Van de Stroet et al. (2019) to determine the impact of N, applied both foliar and broadcast, to the rhizobia nodulation of soybean that had received auxin injury from dicamba and 2,4-D at low rates, found that the addition of N contributed to a decrease in soybean biomass from these herbicides, and following dicamba injury, applications of foliar-applied N contributed to a significant decrease in yield, but not soil-applied broadcast N. At one location, soybean nodulation was not affected while at another nodulation was decreased by 35% for plants treated at V3 and R1 with dicamba (Van de Stroet et al., 2019). When dicamba at 0.014 oz/ac formulated as Clarity® was applied at R1 alone and V3 plus R1 to soybean, biomass was reduced as much as 25% when applied with foliar N 7 days following the R1 Clarity application; biomass reduction was only 10% when treated with foliar N 20 days following the R1 application of Clarity (2019). For soybean not treated with N, biomass reduction averaged 20% (Van de Stroet et al., 2019). The results of crop response to fertilizers following herbicide injury are largely due to the role of nutrients in the crop. Nitrogen, absorbed as nitrate (NO^{3-}) and ammonium (NH^{4+}) by plants, plays a role in the creation of amino acids and proteins, chlorophyll formation, energy transfer, and overall increased vegetative growth (Havlin et al., 2016). Potassium (K) is absorbed as a positive ion (K^+) by plants and is responsible for cell water and transpiration rate regulation, carbohydrate transfer and amino acid synthesis, and is also known to aid rhizobium activity in legumes and improve disease drought resistance (Havlin et al., 2016).

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Soybean is more sensitive to dicamba than any other auxin herbicide (Anderson et al., 2004). With the recent introduction of Xtend® technology and subsequent increase in dicamba use and off-target movement to sensitive crops, such as non-dicamba-resistant soybean, securing a means of preserving yield of dicamba-injured crops could afford producers with greater options when faced with this issue. The objective of this research was to determine if soybean receiving broadcast, soil-applied N and K fertilizer after the manifestation of dicamba injury would hasten soybean recovery from, or mitigate negative yield response to, a low-dose dicamba application.

Procedures

A field experiment was conducted in 2019 at the University of Arkansas System Division of Agriculture's Milo J. Shult Agricultural Research and Extension Center in Fayetteville. The trial was prepared with a disk, hopper, and field cultivator to prepare an optimum seedbed. The soybean cultivar, 'CZ 4820LL', was planted at 140,000 seed/ac in 4-row plots of 25-ft in length and row width of 36 inches. The trial was irrigated as needed. The trial was conducted to determine the impact of broadcasting fertilizers following the manifestation of dicamba symptomology on soybean. The design was a 2-factor factorial with dicamba application timing as factor A (R1, R3, R1 fb R3) and factor B as fertilizer applied 7 days following the dicamba application (none, N only, K only, N plus K) (Table 1). Nitrogen was applied as urea (46%) at 45 lb/ac and K as potassium chloride (50%) at 60 lb/ac. Fertilizer was spread by hand throughout each treatment. The herbicide rate for this trial was 0.003 lb ae/ac, or a 1/150x rate of dicamba, formulated as Xtendimax®, with a 1x rate being 0.5 lb ae/ac. Dicamba was applied to 4-row plots, and drift blockers were used to apply dicamba only to the 2 middle rows of each plot. The trial was initiated on a tilled, bare-ground field and herbicide treatments applied using a CO_2-pressurized backpack sprayer calibrated to deliver 15 gal/ac of spray volume at 40 PSI using TTI 110015 spray tips on a 20-in. spacing. The trial was kept weed-free with herbicides labeled for soybean as well as through the use of row cultivation and hand weeding. Visual estimates of injury were taken at 21 days after application (DAA). Visual injury ratings were based on a scale of 0% to 100%, with 0% representing no injury and 100% representing complete plant death. Biomass (lb.) was collected by removing plants from 3.38 feet of 2 rows from all plots when soybeans reached the R5 growth stage. In each plot, 3.38 feet of biomass was collected from both a row that did receive the dicamba application and a row that was blocked from receiving dicamba; this allowed the main effect of fertilizer type to be compared directly to the non-treated. Collected biomass was dried and weighed by the plot. In addition, grain was harvested at maturity, and grain moisture was measured and corrected to 13% moisture. The relative yield was calculated for each plot by comparing the yield of treated plots to the non-treated plots. All data were subjected to analysis of variance using PROC GLIMMIX in SAS 9.4. A beta distribution was used to analyze injury and biomass data and a gamma distribution for relative yield data.

Results and Discussion

There was a significant interaction of dicamba application timing and fertilizer applied for visual estimations of injury taken at 21 DAA (Table 2). For treatments receiving both N and K, the injury was decreased for soybean treated at R3 compared to treatments not receiving any fertilizer or only nitrogen (Fig. 1). In addition, treatments receiving N only at the R1 application timing had greater injury than other treatments at the same timing; however, all differences between injury according to fertilizer applied were numerically small with no greater than a 5% difference between treatments applied with different fertilizer types across dicamba timings (Fig. 1). Treatments applied with dicamba at both R1 and R3 timings had consistently greater injury compared to all other timings with 76% average injury across fertilizer type (Fig. 1). Treatments applied at R3 had the least injury at 47% average injury across fertilizer type, and treatments applied at R1 alone had 51% average injury across fertilizer type (Fig. 1).

Among biomass collected from the rows of each plot that were not treated with dicamba, there was no effect of any factor, although there was a numerical increase in biomass among non-treated rows that did receive fertilizer with the greatest biomass recorded from plots receiving both N and K (Table 2). Biomass collected from plots receiving dicamba applications had a significant interaction of both application timing and fertilizer applied (Table 2). For R1-applied treatments receiving K only or no fertilizer, biomass was averaged 1.3 lb each, whereas R1-applied plots receiving N had 0.94 lb of biomass and R1-applied treatments receiving both N and K had the lowest biomass at 0.65 lb (Fig. 2). Among R3-applied treatments, there was no significant difference in biomass; however, there was a numerical reduction among treatments receiving both fertilizers compared to other R3 applied treatments (Fig. 2). Among treatments applied with dicamba at both R1 and R3, there was no difference between treatments regardless of fertilizer applied, receiving no fertilizer or only N, these having an average of 0.92 lb. However, among treatments receiving K alone or N plus K, biomass was reduced to an average of 0.75 lb (Fig. 2). Additionally, Treatments receiving no fertilizer had the greatest biomass among plots receiving dicamba with 1.1508 lb when averaged across applicating timings, and were not significantly different from treatments receiving either N or K alone at 1.05 and 1.09 lb, respectively, averaged across application timings. Treatments receiving N plus K had significantly lower biomass compared to treatments receiving other fertilizer applications at 0.85 lb averaged across application timings (data not shown Fig. 2).

The relative yield was significantly affected by application timing with all timings significantly different from each other, excluding treatments receiving dicamba at R1 which were not different from the non-treated plots with a relative yield of 87% (Table 2; Fig. 3). Treatments applied at R3 had a relative yield of 69%, and treatments receiving dicamba at both R1 and R3 timings had significantly lower relative yield compared to other application timings at only 24% of the non-treated (Fig. 3).

Practical Applications

There was a significant decrease in injury among treatments receiving both N and K; however, it was a biologically small difference in injury, whereas dicamba application timing provided the greatest variation among treatment injury (Fig. 1). Fertilizer application did have significant interaction with application timing for biomass data; however, treatments receiving fertilizer applications tended to have reduced biomass versus treatments not receiving fertilizer, with treatments applied with both N and K having the most reduced biomass (Table 2; Fig. 2). In addition, fertilizer additions showed no impact on relative yield (Table 2). Findings from this research suggest that soil-broadcasting fertilizer following soybean injury from off-target dicamba movement will not mitigate final yield loss; however, differences in injury and biomass data did indicate a response from fertilizer inputs. Therefore, further research could provide more efficacious results. Additionally, Cercospora leaf blight (*Cercospora fragariae*) was observed late-season in the trial with higher incidence and severity of disease symptoms observed in plots applied with dicamba when compared with the non-treated. Applications of dicamba made later in the season (R3 vs. R1) appeared to allow increased disease severity. Further research will be needed to draw conclusions from this observation. Dicamba application to vegetative soybean or repeating the experiment with low-dose applications of a different herbicide would be suggested for future research.

Acknowledgments

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Table 1. List of treatments included in the use of nitrogen and potassium fertilizer to mitigate yield loss and injury in a soybean trial conducted at the University of Arkansas System Division of Agriculture's Milo J. Shult Agricultural Research and Extension Center in Fayetteville, Ark., in 2019.

Treatments	Application Timing	Fertilizer Type
1	None	None
2	None	N
3	None	K
4	None	N + K
5	R1	None
6	R1	N
7	R1	K
8	R1	N + K
9	R3	None
10	R3	N
11	R3	K
12	R3	N + K
13	R1 + R3	None
14	R1 + R3	N
15	R1 + R3	K
16	R1 + R3	N + K

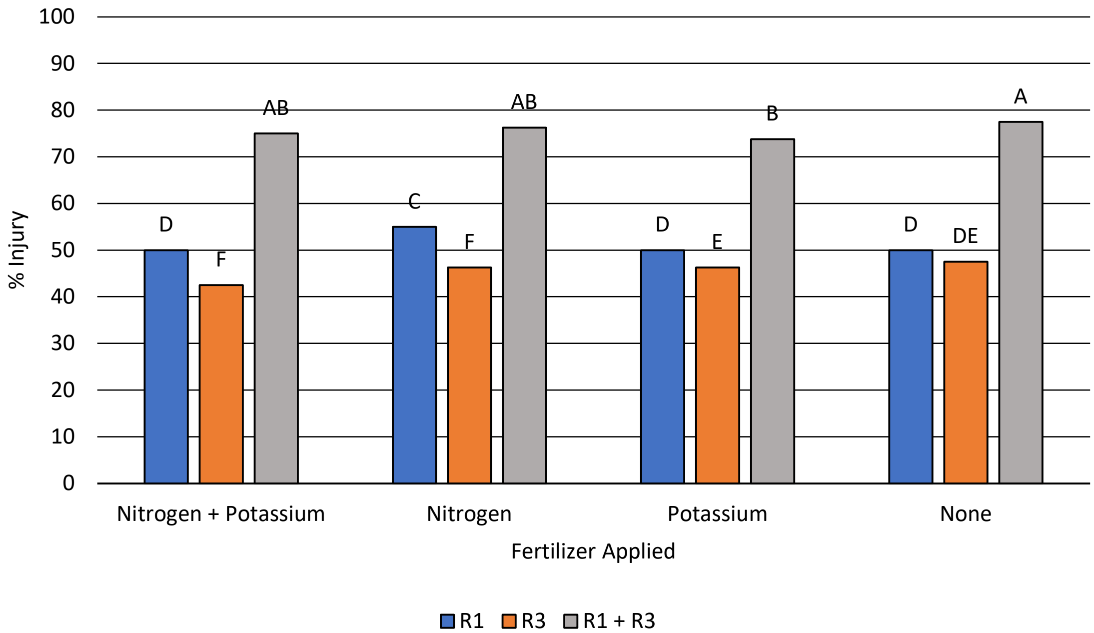

Fig 1. Depiction of injury sustained by soybean plots applied with low-dose dicamba and arranged according to experimental treatment and factor. Treatments with the same letter are not significantly different according to Fisher's protected least significant difference test at α = 0.05.

Table 2. Results of the analysis of variance for factorial experiment conducted for soybean injury at 21 days after dicamba application (DAA), treated biomass data, non-treated biomass data, and yield relative to the non-treated at the University of Arkansas System Division of Agriculture's Milo J. Shult Agricultural Research and Extension Center in Fayetteville, Ark., in 2019. See Table 1 for a list of treatments.

Factors	Injury 21 DAA	Biomass	Relative yield
		lb	%
	------------------------------*P* values-------------------------		
Application Timing	<0.0001[a]	<0.0001	<0.0001
Fertilizer Applied	0.0023	0.0010	0.7097
Application Timing by Fertilizer Applied	0.0273	0.0169	0.8969

[a] *P* values at or smaller than 0.05 level considered significant.

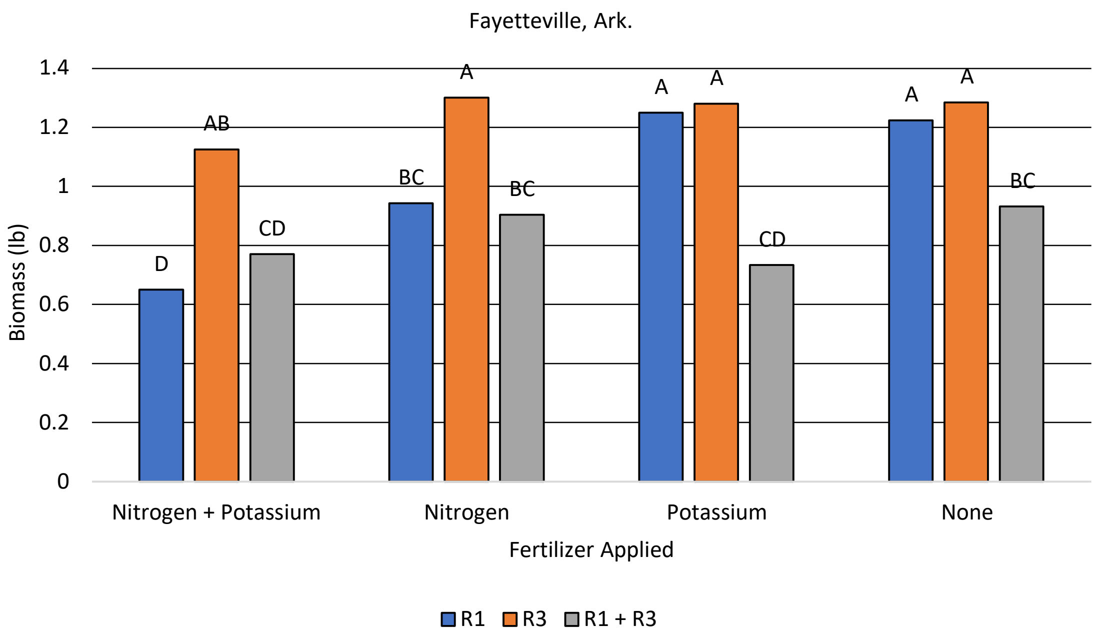

Fig 2. Depiction of plot biomass of soybean treated with low-dose dicamba arranged by treatment and factor. Biomass was recorded in pounds (lb) per 3.38 foot of row. Treatments with the same letter are not significantly different according to Fisher's protected least significant difference test at α = 0.05.

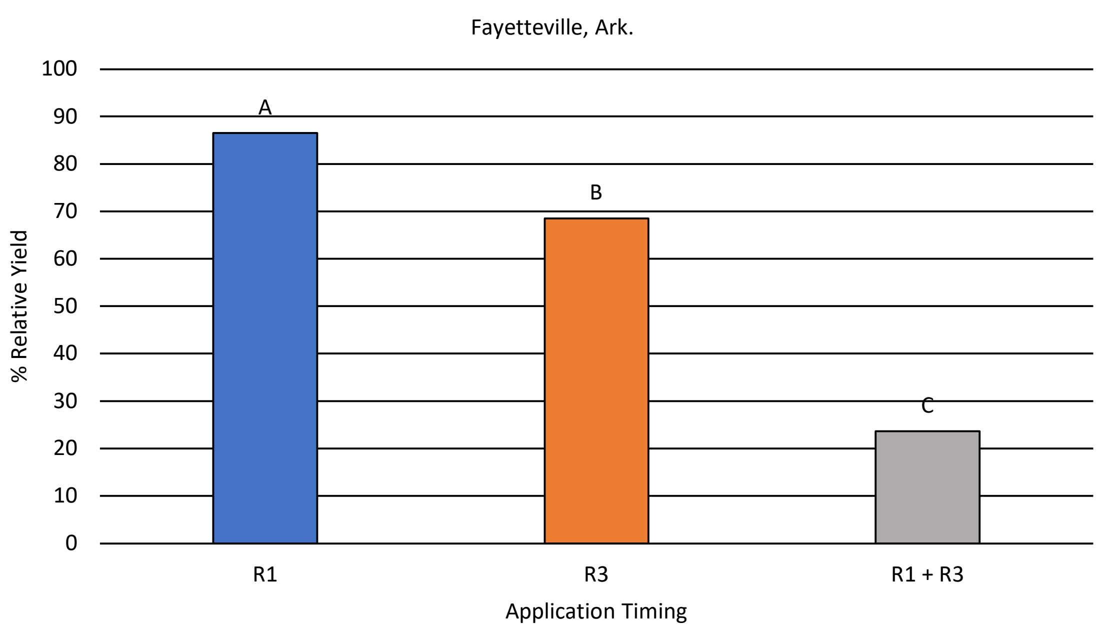

Fig 3. Depiction of the main effect of dicamba application timing to soybean treatments according to the relative yield of each treatment compared to the non-treated. Treatments with the same letter are not significantly different according to Fisher's protected least significant difference test at α = 0.05.

Use of Roller-wiper Applications of Dicamba for Weed Control in Soybean

R.B. Farr,[1] J.K. Norsworthy,[1] G.L. Priess,[1] J.W. Beesinger[1]

Abstract

With recent concerns over the off-target dicamba movement from broadcast applications, alternatives to traditional broadcast herbicide applications are needed. Wick-based, herbicide applications were once used in row crops when control options were limited, and crop tolerance to herbicides was marginal. While applying a herbicide like dicamba through a roller-wiper, the wick-type applicator will not likely reduce the volatility of the herbicide; it would greatly reduce the risk for physical drift from the treated field. In order to investigate the utility of a roller-wiper herbicide applicator in soybean cropping systems, two experiments were conducted to determine the most effective application methods in terms of weed control as well as to determine how these application methods would affect dicamba-resistant soybean. Both experiments were conducted at the Northeast Research and Extension Center using a randomized complete block design with four replications arranged as a 2 × 2 × 3 factorial comparing preemergence options, application timing, and application placement. Palmer amaranth (*Amaranthus palmeri* S. Wats.) control with roller-wiper applications of dicamba was significantly less effective than broadcast applications of dicamba, reducing weed control from 95% control to 89% weed control when wiped within the canopy and 85% control when wiped above the canopy. Soybean was not significantly injured, and soybean yield was not significantly affected as a result of the roller wiper applications. This information will aid producers in determining if using a roller-carpet applicator will be an effective tool in their operations.

Introduction

Concerns regarding the off-target movement of dicamba to non-target vegetation have led producers and applicators to search for creative ways to apply dicamba. Off-target movement of dicamba may be categorized into three separate categories; particle drift, tank contamination, and volatilization (Steckel et al., 2010). One technology that is being considered to reduce particle drift is that of wick/wiping type applicators. Wick and wiping type applicators in the past were typically utilized to remove weeds that grew above the canopy of crops that were not tolerant to the herbicide applied, such as glyphosate above non-glyphosate-resistant soybean for johnsongrass [*Sorghum halepense* (L.) Pers.] control (Keeley et al., 1984; Schneider et al., 1982). By only applying herbicide on what the wiper or wick touches, the risk of particle drift from applicators is greatly reduced.

Procedures

Two separate experiments were conducted in the summer of 2019 at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center at Keiser, Ark. The objective of these studies was to determine the efficacy and crop safety of applications using a roller-wiper applicator compared to broadcast applications. One study assessed the effects of roller-wiper applications on soybean alone, and the other assessed the efficacy of a roller-wiper application on Palmer amaranth (*Amaranthus palmeri* S. Wats.). Both studies were planted with dicamba-resistant Dekalb 49X6 soybean at a population of 140,000 seed/ac. Both studies were conducted as a 2 by 2 by 3-factor factorial with a randomized complete block design. The three factors were the presence or absence of a preemergence herbicide (PRE), the number of postemergence applications (one or two), and the placement of the postemergence applications (above crop canopy, 4 inches inside crop canopy, or broadcast) (Table 1).

The plot size was 6.33-ft wide by 40-ft long with 38-in. row spacing. Broadcast and PRE applications were made using a CO_2-pressurized backpack sprayer at 15 gal/ac using TeeJet® AIXR 110015 nozzles for the PRE applications and TTI 110015 nozzles for the postemergence applications. Inside and above canopy applications were made using a 79-in. GrassWorks® Rotary Weed Wiper mounted on the back of a

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tractor applying a 30% solution of Engenia® (dicamba) by volume. The first postemergence applications were made when the soybean plants were 16 in. tall and the Palmer amaranth measured 4 in. to 24 in. tall, with the second postemergence applications being made 14 days after the first postemergence application.

At the time of the second application, the soybean measured 24 in. in height, and the Palmer amaranth measured 24–26 in. tall. All broadcast applications of dicamba were at 560 g ae/ha. Visual estimations of weed control and crop injury were taken at 21 days after final treatment on a 0%–100% scale with 0 being no injury or control and 100 being plant death. Soybean yield was collected at harvest from each plot at maturity. Data were analyzed using the fit model platform in JMP Pro 14.2 and subjected to analysis of variance with means separated using Fisher's protected least significant difference test ($\alpha = 0.05$).

Results and Discussion

The results from this study suggest that there were significant differences in Palmer amaranth control as the result of the treatments in this study. In terms of Palmer amaranth control, no significant interactions between factors occurred, but the preemergence factor and the placement factors were both significant at 21 days after treatment. The use of a PRE herbicide increased Palmer amaranth control from 83% control to 97% with the use of S-metolachlor compared to no preemergence herbicide when averaged over application placement and timing (Fig. 1). In terms of application placement, both roller-wiper applications were less efficacious than the broadcast application treatments, averaged over the timing and PRE option, but the two different roller-wiper application placements were not different from each other. Palmer amaranth control was reduced from 95% control with the broadcast application down to 89% control for the in-canopy roller-wiper application and 87% control for the above canopy application (Fig. 2). This difference may be attributed to the inability of the roller-wiper to reach plants shorter than the application height, as only weeds that contacted the wiper were controlled (Figs. 3 and 4). In terms of soybean crop safety, there were no differences in visible crop injury through 21 days after application. There were also no differences in soybean yield between all the factors and no significant interactions (Fig. 5). When comparing placement, the above canopy roller-wiper application effectively served as a non-treated application as the soybean was not wiped in these applications and was statistically similar to the other placement methods.

Practical Applications

The results from this study suggest that roller-wiper applications of dicamba are safe for use in dicamba-resistant soybean, as there was no significant injury or reduction in yield. In terms of weed control, the results from this study displayed the limitations of roller-wiper applications in relation to broadcast applications. This study also relayed the importance of utilizing residual herbicides at planting.

Acknowledgments

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Table 1. Programs and treatments for both experiments at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center at Keiser, Arkansas.

Program	PRE	POST 1	POST 2	POST Placement
	g ai/ha	% v/v or g ai/ha	% v/v or g ai/ha	
1		Non-treated		
2	None	Dicamba (30%)[a]	None	Above Canopy
3	*S*-metolachlor (1068)[b]	Dicamba (30%)	None	Above Canopy
4	None	Dicamba (30%)	Dicamba (30%)	Above Canopy
5	*S*-metolachlor (1068)	Dicamba (30%)	Dicamba (30%)	Above Canopy
6	None	Dicamba (30%)	None	Inside Canopy
7	*S*-metolachlor (1068)	Dicamba (30%)	None	Inside Canopy
8	None	Dicamba (30%)	Dicamba (30%)	Inside Canopy
9	*S*-metolachlor (1068)	Dicamba (30%)	Dicamba (30%)	Inside Canopy
10	None	Dicamba (560 g)[c]	None	Broadcast
11	*S*-metolachlor (1068)	Dicamba (560 g)	None	Broadcast
12	None	Dicamba (560 g)	Dicamba (560 g)	Broadcast
13	*S*-metolachlor (1068)	Dicamba (560 g)	Dicamba (560 g)	Broadcast

PRE = Preemergence; POST = Postemergence.

[a] Xtendimax® at a concentration of 2.9 lb per gal.

[b] Dual Magnum® applied at 16 fl oz/ac.

[c] Xtendimax applied at 22 fl oz/ac.

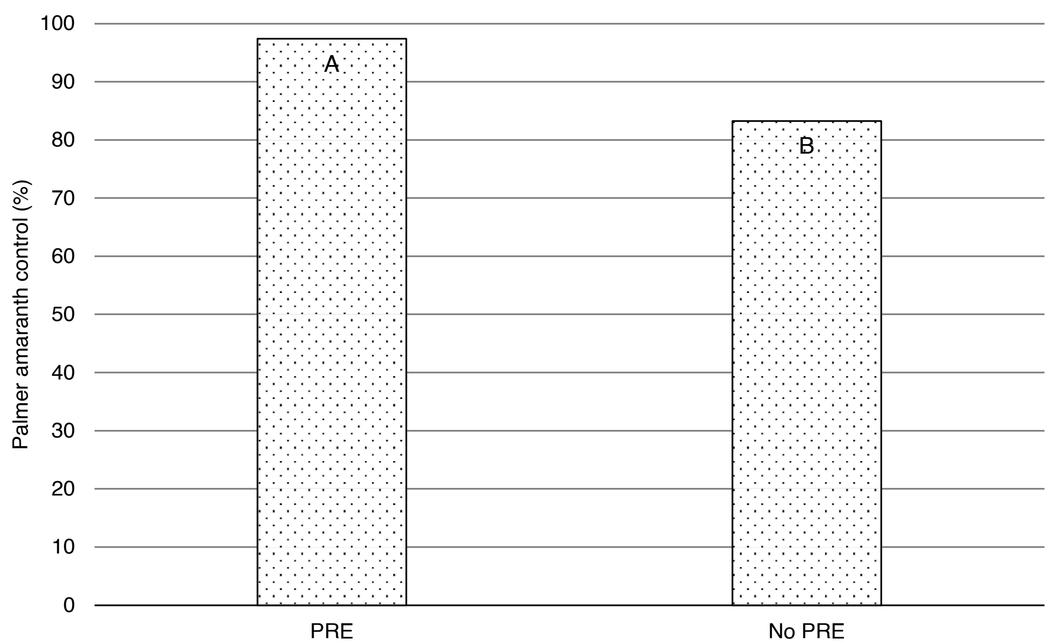

Fig. 1. Percent Palmer amaranth control 21 days after application by preemergence option averaged over placement and timing. Treatments with the same letter are not significantly different according to Fisher's protected least significant difference test at α = 0.05

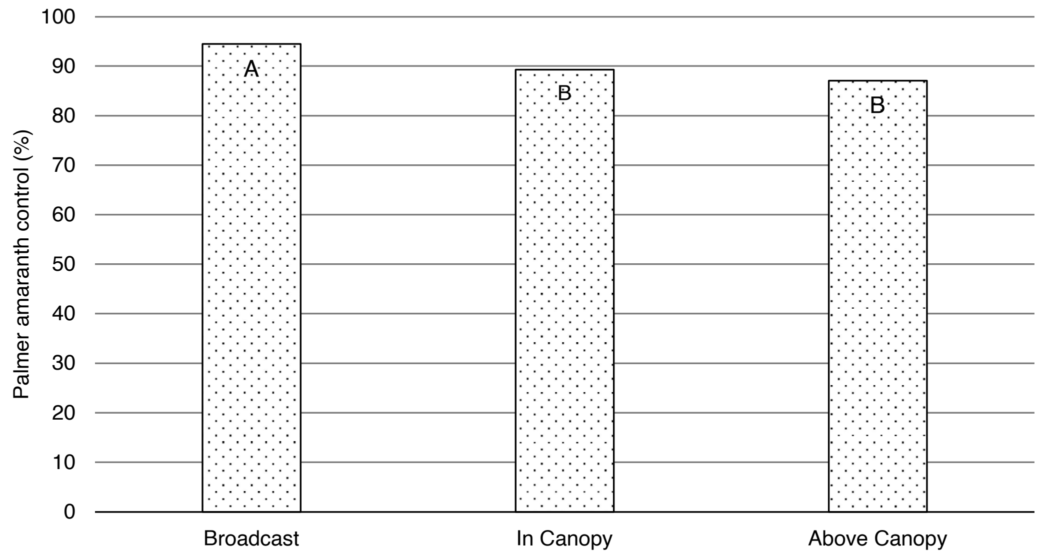

Fig. 2. Percent Palmer amaranth control 21 days after application by placement averaged over preemergence option and timing. Treatments with the same letter are not significantly different according to Fisher's protected least significant difference test at α = 0.05

Fig. 3. Palmer amaranth in broadcast-treated plot 14 days after application.

Fig. 4. Palmer amaranth in above- canopy treated plot 14 days after application.

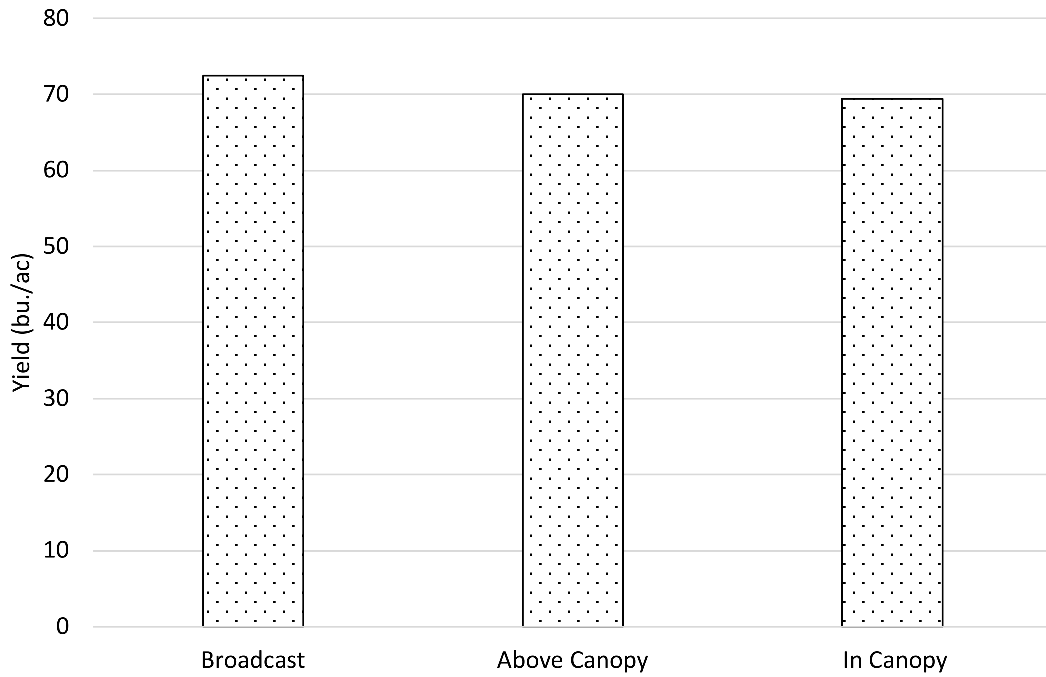

Fig. 5. Soybean yield (kg/ha) by application placement averaged over preemergence option and timing. NS = not significant.

Control of Palmer Amaranth using Multiple Residual Herbicides With and Without *S*-metolachlor

M.C. Castner,[1] J. K. Norsworthy,[1] O.W. France,[1] G.L. Priess,[1] and R.B. Farr[1]

Abstract

Midsouth soybean producers are currently challenged with few postemergence (POST) chemical control options for Palmer amaranth [*Amaranthus palmer*i (S.) Wats]. In order to mitigate selection pressure placed on POST herbicides, producers are encouraged to begin weed-free through the intensive use of preemergence (PRE) herbicides as well as overlap residual herbicides during POST applications. Overlapping residual herbicides with POST applications has proven to be an effective approach in reducing the density of weed escapes to be controlled by limited POST options. However, confirmation of *S*-metolachlor resistant Palmer amaranth may provide producers with additional challenges. In order to evaluate the efficacy of multiple residual herbicides in combination with *S*-metolachlor on a metolachlor-resistant biotype under field conditions, a two-factor experiment was conducted near Crawfordsville, Arkansas in 2019, with the first factor being herbicide combination (acetochlor at 32 fl oz/ac and pyroxasulfone at 1.1 oz/ac) and the second being *S*-metolachlor rate (0, 1 and 1.33 pt/ac). Palmer amaranth visible estimates of control and density were taken 28 days after treatment (DAT) and were used to evaluate the efficacy of all combinations of herbicide and rate. The addition of acetochlor and pyroxasulfone to all rates of *S*-metolachlor improved Palmer amaranth control 28 DAT compared to *S*-metolachlor alone, especially mixtures including pyroxasulfone. *S*-metolachlor at 1.33 pt/ac plus pyroxasulfone demonstrated 90% control compared to 41% control with *S*-metolachlor as a stand-alone treatment. Palmer amaranth densities adequately reflected visual estimates of control at the same date, further indicating the value of mixing PRE herbicides with the onset of *S*-metolachlor resistance.

Introduction

Mid-south producers continue to face limited postemergence (POST) weed control options for multiple-resistant Palmer amaranth [*Amaranthus palmeri* (S.) Wats.] in soybean production (Heap 2020). Producers are encouraged to reduce the selection pressure of POST-applied herbicides by beginning weed-free through the intensive use of preemergence (PRE) herbicides. Overlapping residual herbicides with POST applications have proven to be an effective approach in reducing the number of weed escapes being controlled by limited POST options. However, with numerous soybean acres utilizing an *S*-metolachlor-based weed control program in Arkansas, confirmation of *S*-metolachlor resistant Palmer amaranth may provide producers with additional challenges (Brabham et al. 2019). Ultimately, producers need to be cognizant of *S*-metolachlor resistance and use PRE herbicides with alternative sites of action to increase the longevity of *S*-metolachlor and other essential very-long-chain fatty acid elongase (VLCFA)-inhibiting herbicides.

Procedures

In order to investigate the utility of multiple VLCFA-inhibiting herbicides on suspected *S*-metolachlor resistant biotypes of Palmer amaranth, a bare-ground field experiment was conducted near Crawfordsville, Arkansas in 2019. Treatments were arranged as a two-factor factorial (herbicide combination by *S*-metolachlor rate) randomized complete block design with four replications. A burndown application was made consisting of paraquat at 40 fl oz/ac to eliminate all standing vegetation before treatment applications. All treatments were made to bare ground plots measuring 6-ft in width (2 rows) by 20-ft in length with a CO_2-pressurized sprayer equipped with TeeJet AIXR110015 nozzles, calibrated to deliver an output of 15 gal/ac. Visible estimations of control of Palmer amaranth were taken 28 days after treatment (DAT) on a scale of 0% to 100%, with 0% representing no control and 100% representing complete control. Additionally, Palmer amaranth density counts were collected 28 DAT using one 3 ft^2 quadrant per plot. All data were subjected to analysis of

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variance in JMP Pro 14.3 using Fisher's protected least significant difference test (α = 0.05).

Results and Discussion

Overall, control of Palmer amaranth from *S*-metolachlor as a stand-alone herbicide was minimal in comparison to mixtures with other PRE herbicides. *S*-metolachlor at 1 and 1.33 pt./ac provided 31% and 41% control 28 DAT, respectively, whereas *S*-metolachlor-containing mixtures with pyroxasulfone demonstrated 82% and 90% control at the same interval (Fig. 1). These data are consistent with findings from Brabham et al. (2019), documenting reduced efficacy and evolution of resistance to *S*-metolachlor in contrast to other VLCFA-inhibiting herbicides. Compared to *S*-metolachlor and pyroxasulfone mixtures, benefits of less magnitude were seen with the addition of acetochlor to *S*-metolachlor, although maintaining greater control than *S*-metolachlor alone (Fig. 1). Although Palmer amaranth densities appear to reflect percent control ratings at 28 DAT, plant densities were only reduced when 1.33 pt/ac *S*-metolachlor was combined with pyroxasulfone (Fig. 2).

Practical Applications

S-metolachlor is a foundational PRE- and POST-applied residual control herbicide utilized in Arkansas soybean production, and failure to control early-season Palmer amaranth applies immense selection pressure on already limited POST herbicide options. This research shows the importance of mixing PRE herbicides to maintain acceptable levels of control. However, mixtures containing herbicides with the same site of action (SOA) may not be a sustainable approach in weed populations that show the reduced activity of *S*-metolachlor. More research is needed to determine if resistance to *S*-metolachlor confers resistance to other families within the same SOA, and additional studies are needed to address alternative PRE options for producers facing reduced activity of *S*-metolachlor.

Acknowledgments

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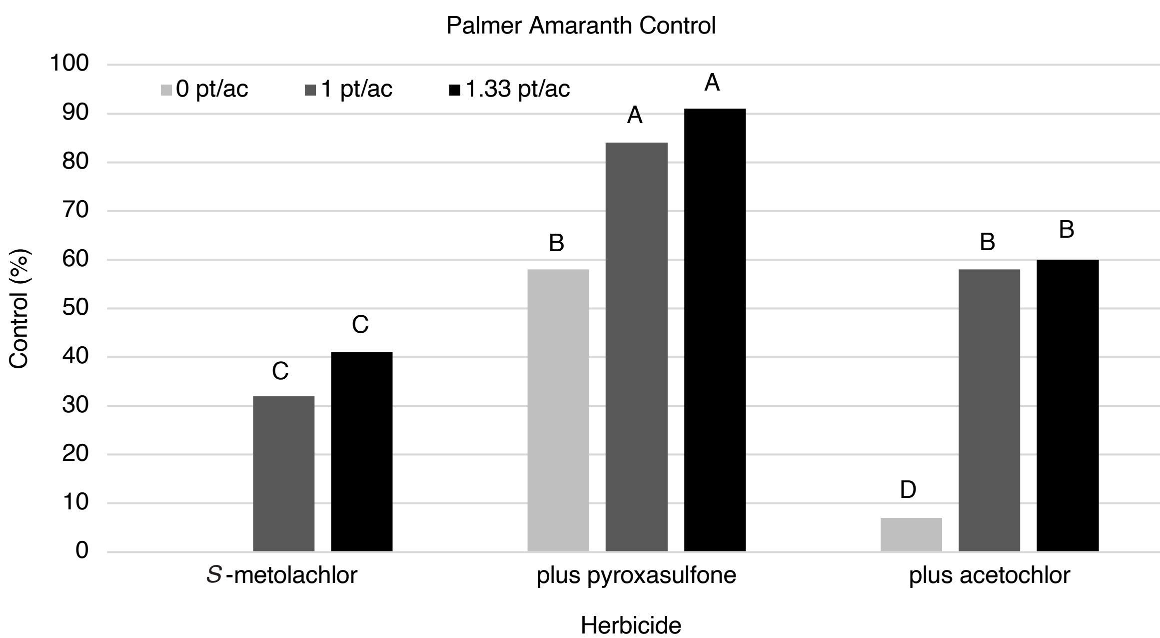

Fig. 1. Comparison of Palmer amaranth control 28 days after treatment with *S*-metolachlor and *S*-metolachlor-containing mixtures near Crawfordsville, Arkansas, in 2019. Means followed by the same letter are not significantly different (α = 0.05).

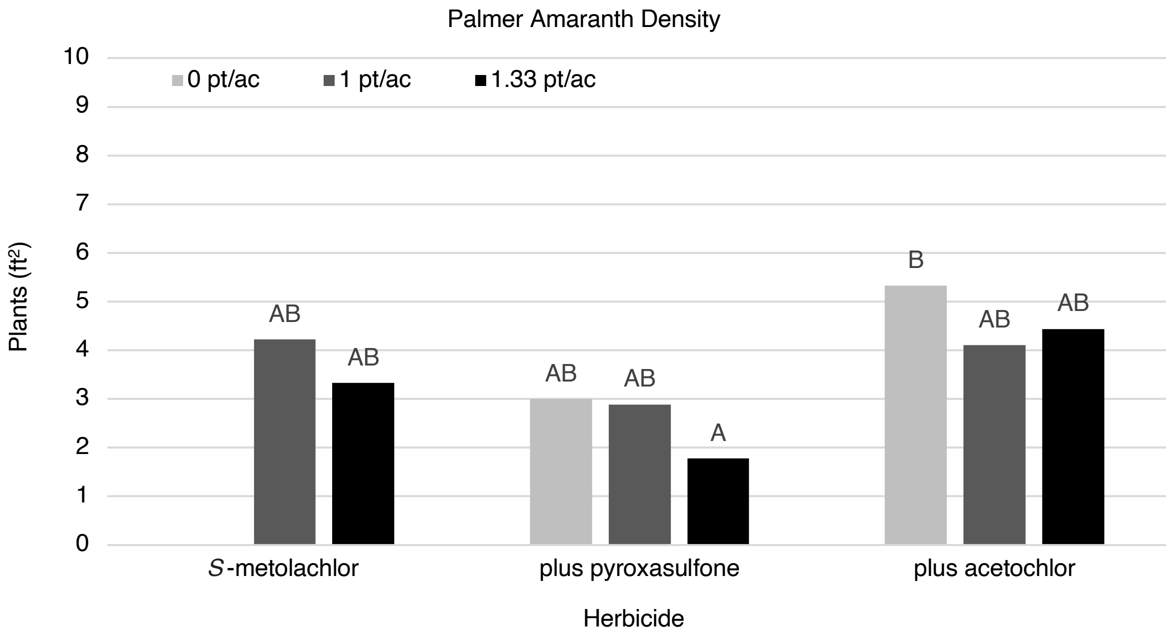

Fig. 2. Comparison of Palmer amaranth densities 28 days after treatment with *S*-metolachlor and *S*-metolachlor-containing mixtures near Crawfordsville, Arkansas, in 2019. Means followed by the same letter are not significantly different (α = 0.05).

Status of Palmer amaranth Resistance to S-Metolachlor in Arkansas: Does High Use Induce Accelerated Degradation?

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Abstract

General screening of Palmer amaranth (*Amaranthus palmeri*) accessions, collected across Arkansas, was conducted to determine their response to *S*-metolachlor (*S*-moc). Thirty-five accessions were sprayed with 1 lb ai/ac. In a second experiment, ten soil samples were collected from five counties in paired fields (low versus high use of *S*-moc). A field experiment was conducted at the University of Arkansas System Division of Agriculture's Milo J. Shult Agricultural Research and Extension Center in Fayetteville to evaluate the effect of the preemergence application on the dissipation of *S*-moc. Palmer amaranth responded differently to *S*-moc, with three accessions showing significantly less susceptibility. *S*-metolachlor half-lives from pooled data across locations were 6.5 and 12.7 d for low and high use, respectively. Half-lives were the same (12.5 ± 0.93 d and 12.3 ± 1.4 d) with or without preemergence *S*-moc. Resistance to *S*-moc is incipient. Immediate, prior application of *S*-moc (preemergence) does not accelerate the dissipation of *S*-moc applied to the same soil 57 days later, in the laboratory. Thus, short-term *S*-moc use does not induce accelerated dissipation. Preliminary data show that *S*-moc applied to the soil from five grower fields with long-use history degrade 2 times slower than *S*-moc applied to the soil from five fields with low-use history.

Introduction

Residual herbicides are among the best tools to manage resistant or recalcitrant weeds because they extend the weed control period (Norsworthy et al., 2012). Therefore, weed resistance to residual herbicides is a major concern. Resistance to *S*-metolachlor (*S*-moc) in Palmer amaranth has been reported in Arkansas (Brabham et al., 2019). However, the spread of resistance at the state level has not been investigated. Resistance to *S*-moc may be aided by accelerated degradation of the herbicide owing to the adaptation of the soil microbial population. Accelerated degradation of soil-applied herbicide has resulted from the adaptation of microbes that use herbicides as an energy source. *S*-metolachlor is one of the most widely used residual herbicides in the U.S. and worldwide. It is primarily degraded by microbes (Liu et al., 1991). Repeated application of some residual herbicides (i.e., atrazine) has resulted in enhanced herbicide degradation (Abit et al., 2012; Fryer and Kirkland, 1970; Mueller et al., 2017; Parker et al., 2018; Shaner and Henry, 2007; Zablotowicz et al., 2007) and reduced weed control (Harvey et al., 1987; Harvey et al., 1986). The effect of *S*-moc application history on its dissipation has not been studied thoroughly. In India, the half-life of *S*-moc shortened after four applications over 8 months. (Sanyal and Kulshrestha, 1999). However, the relationship between *S*-moc degradation rate and use history across years and locations is not clear (Shaner and Henry, 2007). Palmer amaranth (*Amaranthus palmeri*) has an extended germination behavior, which increases the likelihood of evolving resistance in the presence of accelerated soil dissipation. *S*-metolachlor is frequently used in split applications and used every year in many crops. Has intensive use finally enriched the microbial population for faster degradation of *S*-moc? The objectives of this research were to determine 1) the status of Palmer amaranth resistance to *S*-moc in Arkansas; 2) if the prior in-season application could serve as a "priming" event that could accelerate the degradation of subsequent applications, and; 3) if high use across years would result in faster degradation of *S*-moc in spiked soils in comparison to low use.

Procedures

Thirty-five Palmer amaranth accessions were collected in fall 2018. General screening of *S*-metolachlor efficacy was conducted in the greenhouse at the University of Arkansas System Division of Agriculture's Milo J. Shult Agricultural Research and Extension Center (SAREC), Fayetteville, using a completely randomized design with 3 replicates in space and was repeated once in time. The screening assay had 2 treat-

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ments (treated and nontreated). *S*-metolachlor was applied at 1.0 lb ai/ac in a spray chamber equipped with Teejet flat fan nozzle TP800067 calibrated to deliver 20 gal/ac at 40 PSI and 1 mph speed. The experimental unit was one tray filled with field soil and planted with 100 seeds. Field soil (Roxana silt loam, 18.8% sand, 68.2% silt, and 12.9% clay) with a low *S*-moc use history was collected from the University of Arkansas System Division of Agriculture's Vegetable Research Station, near Kibler, Ark. *S*-metolachlor was activated shortly after herbicide application by sprinkler irrigation. Also, soil samples were collected from five counties in the spring of 2018 from 10 paired fields (low and high use history of *S*-moc) within the same soil series. Additionally, a field experiment followed by a laboratory incubation experiment was conducted in the summer of 2019 at the SAREC to evaluate the effect of the prior in-season application of *S*-moc on the dissipation of the herbicide in spiked soil in the laboratory. Total daily precipitation and average daily air temperature were acquired from the nearest weather station for the duration of the field study (Fig. 1). The field study was conducted as a randomized complete block with two treatments (*S*-moc preemergence and a non-treated control) replicated four times. Herbicide treatments were applied using a CO_2 pressurized backpack sprayer delivering 20 gal/ac at 40 PSI with a spray boom fitted with a flat fan XR8002 nozzle. Preemergence application of *S*-moc (1.2 lb/ac) was made within 2 days after planting, and the field was irrigated at 0.5-in. within 24 hours after application by sprinkler irrigation. Weeds were managed with glyphosate applied over the entire experiment. Soil samples were collected 57 d after preemergence application of *S*-moc at 4-in. depth from the middle soybean rows. Soil samples from paired fields (spring 2018) and a field experiment in Fayetteville (summer 2019) were sieved, and 500 g of each sample was spiked with 0.75 ppm of analytical grade *S*-moc and incubated in duplicates in a growth chamber at 25 ºC and 100% relative humidity. *S*-metolachlor dissipation was evaluated at 6 time points (0, 3, 7, 14, 28, 56 days after spiking) for the growers' field samples and 7 time points (0, 1, 4, 7, 14, 28, 56 days after spiking) for the Fayetteville field experiment. The concentration of *S*-moc in each subsample was analyzed with a triple quadrupole Shimadzu TQ8040 Gas Chromatograph Mass Spectrometer using helium as the mobile phase.

The screening study data were analyzed using the GLIMMIX procedure in SAS v. 9.4 (SAS Institute, Cary, N.C.). The *S*-moc degradation data from the field experiment in Fayetteville were fitted with the Gustafson-Holden biphasic degradation model (Eq. 1),

$$C = \frac{C_0}{(t/\beta+1)^{\alpha}} \qquad \text{Eq. 1}$$

calculated as a percent of initial concentration, with the initial concentration representing 100%, using nonlinear least-squares in R version 3.6.2 (R Core Team 2019). Half-life values were calculated using Eq. 2.

$$t_{1/2} = \beta(2^{(1/\alpha)} - 1) \qquad \text{Eq. 2}$$

Where C is the concentration of the herbicide at time t, C_0 is the concentration of the herbicide at time t = 0, and α and β are model parameters. For the growers' field samples, data were pooled across locations for high use or low use, and the statistical analysis procedure was used.

Results and Discussion

Palmer amaranth accessions responded differently to the labeled dose (1 lb ai/ac) of *S*-moc. Three accessions WOO-B, PHI-C, and CR-D showed a significant decrease ($P < 0.0001$) in response to the labeled rate of *S*-moc (Kouame et al., 2019). The three accessions were confirmed resistant to *S*-moc with a resistance level of 3- to 4.5-fold (Kouame et al., 2019). *S*-metolachlor half-life values in soil from growers' fields, pooled across locations, were 6.5 and 12.7 d for low-use and high-use fields, respectively (Fig. 2). For the field experiment in Fayetteville, the half-life values were 12.5 ± 0.93 and 12.3 ± 1.4 d for preemergence and non-treated control, respectively (Fig. 3). S-metolachlor values reported in this study are within the range of values reported in the literature. In Mississippi, Kentucky, and Tennessee, the *S*-moc half-life value was 13.7 days (Mueller et al., 1999). In eastern Colorado, the values were between 10.6 and 28.2 days (Shaner and Henry, 2007). In Georgia, averaged over two years, *S*-moc half-life values were 2 d in bare soil and 4 d in soil under low-density polyethylene (LDPE) mulch (Grey et al., 2007). In Tennessee, *S*-moc half-life could be between 8.8 and 27 d (Mueller and Steckel, 2011). In our study, *S*-moc dissipation in spiked soils did not differ between samples from plots treated with *S*-moc preemergence and those from the non-treated plots. However, the dissipation rate of *S*-moc in soils with high-use history, pooled across five locations, was 2 times slower compared to that of low-use history soils in Arkansas. Nevertheless, the half-life values were still within the wide range of dissipation rates of *S*-moc across various regions. One study in India, however, showed an increased dissipation rate of *S*-moc with time when applied repeatedly over 8 months (Sanyal and Kulshrestha, 1999). Our dataset was preliminary and small (as dictated by the scope of initial research), consisting only of five fields each of low- and high-use history situations. Many factors are affecting microbial population dynamics in the field, as they relate to *S*-moc degradation, that we have not yet studied. Among these are soil types, soil sampling time, and rainfall and irrigation events. Prior in-season application of *S*-moc did not accelerate the dissipation of *S*-moc applied to such soil about two months later. It was shown in previous research that metolachlor is degraded only biologically (Accinelli et al., 2001). Microorganisms do not use metolachlor directly as a carbon source; rather, metolachlor degradation is dependent on the presence of another carbon source, suggesting that the herbicide is only co-metabolized as the microbial population uses another compound for sustenance (Bailey and Coffey, 1986; Stamper and Tuovinen, 1998).

Practical Applications

Resistance to *S*-moc is incipient and not yet widespread. It seems that degradation by microbes is not a significant factor in the evolution of resistance to *S*-moc in Palmer amaranth. The significantly higher (2 times) of *S*-moc degradation rate across fields of low-use history compared to those with high-use history contradicted our expectation of what would happen if the microbial population has been enriched by the consistent, intermittent supply of *S*-moc as a food source. We do not know if this pattern will hold across a larger representation of fields in Arkansas, sampled at an optimized timing to detect microbial activity after *S*-moc application in growers' fields. For now, it seems that the loss of Palmer amaranth control is not a direct result of accelerated *S*-moc dissipation after intensive use. Improved management of Palmer amaranth, in general, will keep the evolving resistance to *S*-moc from becoming worse. Therefore, the implementation of an integrated weed management program that reduces the frequency of *S*-moc application is necessary to reduce the selection pressure on Palmer amaranth populations. Field scouting and prevention of remnant Palmer amaranth from producing seeds are necessary to reduce the soil seed bank.

Acknowledgments

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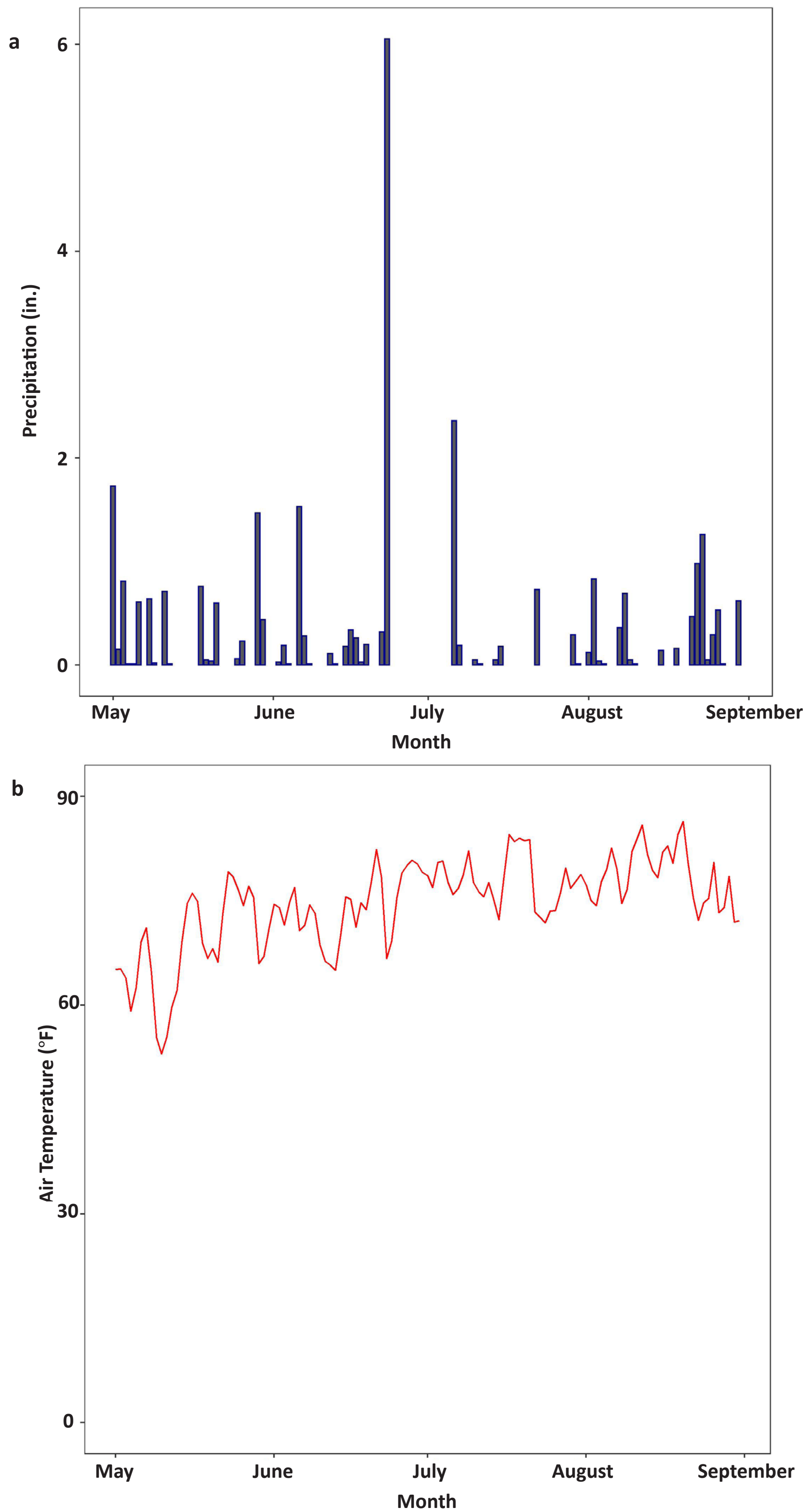

Fig. 1. (a) Average total daily precipitation (in.) and (b) average daily temperature (°F) acquired from the nearest weather station at the University of Arkansas System Division of Agriculture's Milo Shult Agricultural Research and Extension Center, Fayetteville, Arkansas from May to September, 2019.

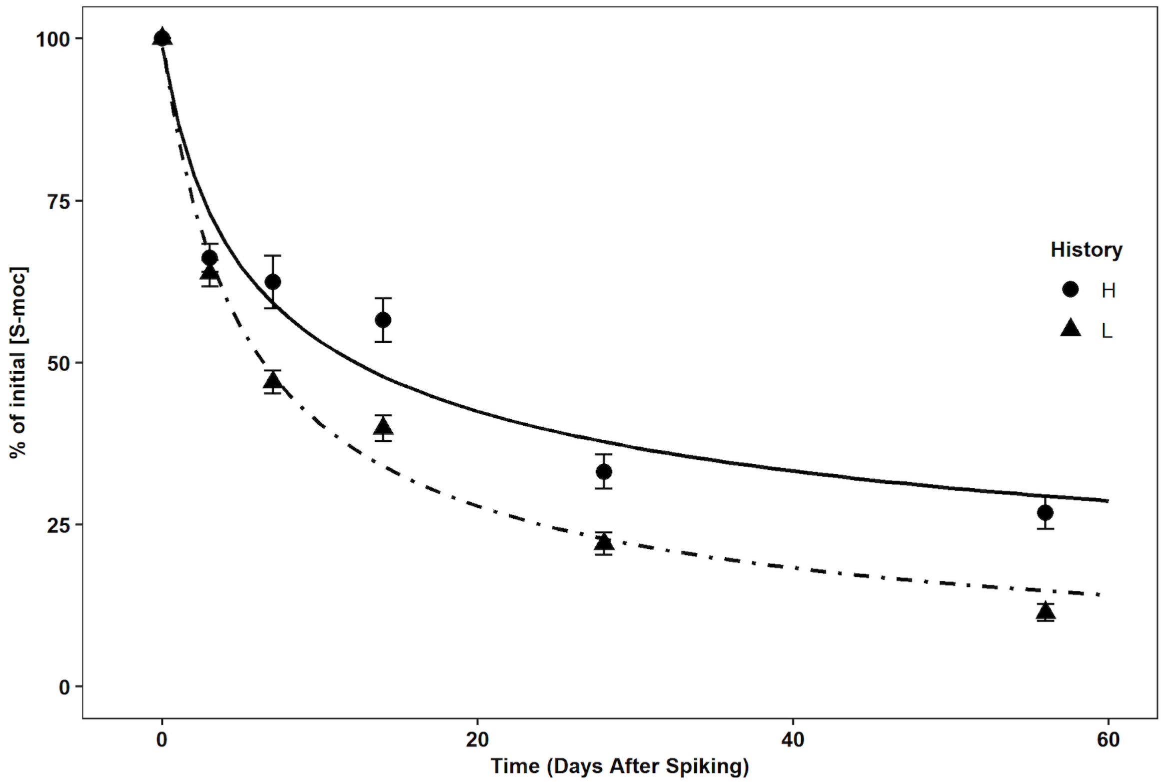

Fig. 2. Effect of use history on *S*-metolachlor dissipation from 10 paired fields from Arkansas. Closed circles are fields with high-use history. Closed triangles are the corresponding field-pairs with low-use history from the same locality and soil series. Data points are averages of five locations.

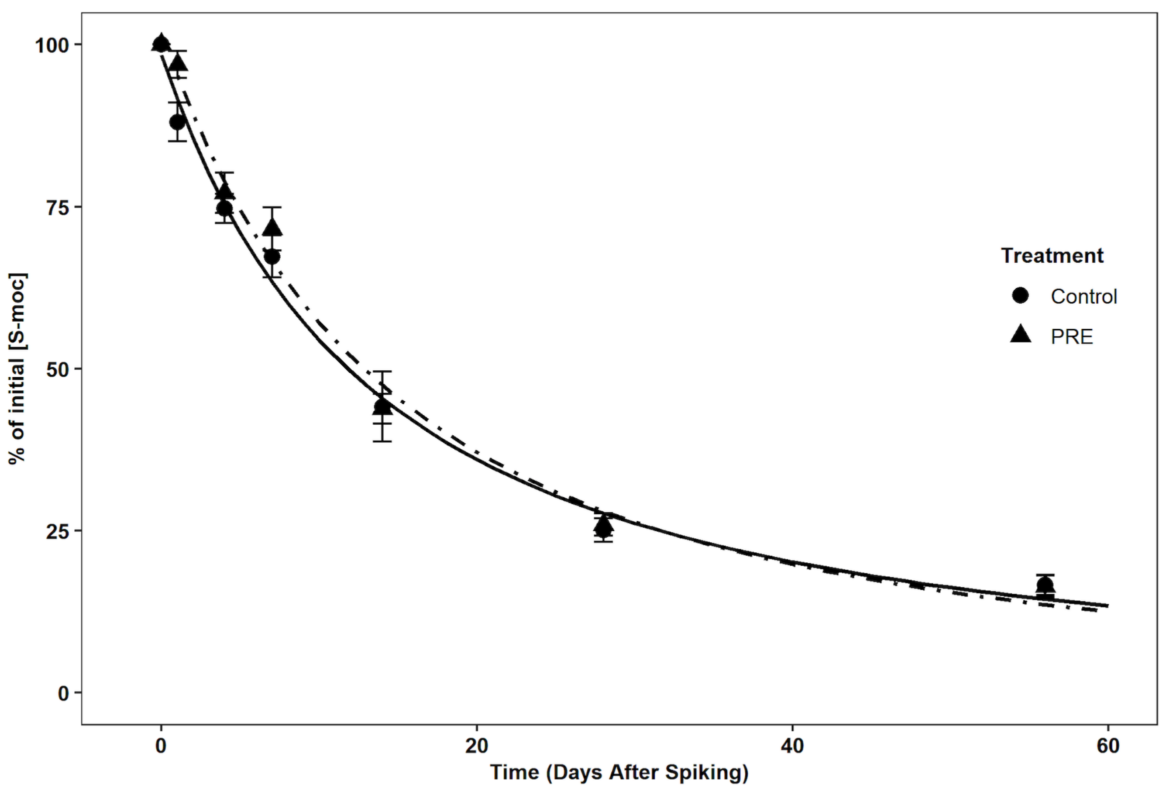

Fig. 3. Effect of preemergence application of *S*-metolachlor on the dissipation of the herbicide in spiked soil, 57 days after preemergence application in a field study at the University of Arkansas System Division of Agriculture's Milo Shult Agricultural Research and Extension Center, Fayetteville, Arkansas from May to August 2019. The herbicide was applied to soybean.

Accelerated Development of Bioherbicides to Control Palmer Amaranth (Pigweed)

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Abstract

Palmer amaranth (*Amaranthus palmeri*), commonly referred to as Palmer pigweed, is highly invasive throughout Arkansas and significantly impacts soybean, corn, and cotton production statewide. Numerous attributes of pigweed make it a formidable weed pest, including high levels of seed production per individual plant, the longevity of seeds upon entry into soil seed banks, rapid reproductive development, hardiness in diverse environmental conditions, high levels of genetic variability, and the capacity to develop resistance to diverse herbicides. The arsenal of tools currently available to control pigweed is largely insufficient and/or environmentally unsustainable. Thus, novel tools to control Palmer pigweed are needed urgently. Native, host-specific pathogens of Palmer pigweed could potentially be developed into effective bioherbicides, especially if the virulence of pathogens can be increased through non-transgenic methods. Thus, the objectives of this research were to 1) evaluate fungal pathogens of Palmer pigweed to identify highly aggressive isolates (potential bioherbicide strains) 2) increase the aggressiveness of selected isolates through molecular genetic (non-transgenic) approaches, and 3) evaluate modified strains and select candidates to commercialize as bioherbicides of pigweed. To this end, over 200 strains of pathogenic fungi have been collected from Palmer pigweed throughout Arkansas and evaluated for virulence in greenhouse trials. Several promising strains have been identified, including *Colletotrichum* isolates that aggressively attack Palmer pigweed, but do not infect soybean or other crop plants. Efforts are underway to increase the virulence of this fungus and other potential bioherbicide candidates through molecular genetics, with the ultimate goal of creating a highly virulent, non-transgenic bioherbicide that induces lethality in Palmer pigweed.

Introduction

Herbicide-resistant weeds are the most problematic and expensive management issues in row-crop agriculture (Perotti et al., 2020). Following the introduction of the Roundup Ready® system in the mid-1990s, up to 164 million acres of U.S. crops have become infested with glyphosate-resistant weeds–essentially the nation's entire row-crop acreage (Anonymous, 2016). Worldwide, in more than 37 countries, there are 38 documented glyphosate-resistant weed species across 34 different crops (Heap and Duke, 2017).

The most egregious herbicide-resistant weeds belong to the genus Amaranthus, which includes waterhemp [*Amaranthus tuberculatus* (Moq.) J.D. Sauer] and other pigweeds (Heap, 2014; Heap and Duke, 2017). Of these, the worst is Palmer amaranth (*Amaranthus palmeri* S. Watson), now considered the most destructive and widely distributed weed in U.S. row crop agriculture. This weed has become a flashpoint for herbicide resistance, even extending to the political and social environments of agricultural communities. For example, attempts to manage Palmer pigweed have caused at least one homicide directly attributable to cross-farm drift problems from illegal herbicide use (Clayton, 2016).

The propensity of Palmer pigweed to quickly develop resistance to diverse herbicides highlights the need for new management tools. One such alternative is offered by developing biological control agents into commercial control products, e.g., biopesticides. The development of biopesticides, including fungal biocontrols, has relied on identifying highly aggressive strains among native populations (Butt and Copping, 2000; Melnick et al., 2011; Templeton, 1988). Promising strains are then screened through a series of well-established tests, including host range, field efficacy, environmental requirements, shelf life, application, and commercial scale-up production. Although biopesticide development has ebbed and flowed somewhat over the years, there have been some notable successes, especially concerning bioinsecticides, biofungicides, and, more recently, bionematicides.

Bioherbicide development has lagged somewhat compared to other categories of biopesticides. The key issue is that virulent fungal biocontrol candidates are often deficient in other critical areas required for successful commercializa-

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tion (Hallett, 2005). Such shortcomings can include instability, environmental susceptibility, inefficient production, reduced overall fitness, and unacceptable host ranges. Thus, there is often a 'natural limit' among candidate strains found within native fungal populations. However, by utilizing non-transgenic genome editing to circumvent these shortcomings, this project provides a new avenue to customize biocontrol agents for Palmer pigweed that balance durability, limited host range (not pathogenic on crops), and heightened aggressiveness on pigweed.

Procedures

An overview of the project approach is provided in Fig. 1. Diseased pigweed plants were collected throughout Arkansas in 2016–2019. Collections will continue in 2020. Plants showing visual symptoms of the disease (leaf spots, stem lesions, or vascular wilts) were collected in sterile plastic bags and stored on ice until isolations were performed. In order to isolate pathogens, diseased plant material was surface sterilized by rinsing with deionized water, 70% isopropanol, 20% bleach water + Tween® 20, and sterile water. Pathogens were isolated from lesions on stems and leaves onto fresh, sterile media (V8 or potato dextrose agar amended with carbenicillin at 100 µg/mL to deter bacterial growth). All fungal cultures were tentatively identified based on morphological characteristics, cataloged, and placed in cryogenic storage until disease screens were performed.

In order to identify promising biological control strains, pigweed seeds were surface sterilized and/or prepared (e.g., scarified) to ensure disease-free seedlings and maximize germination. A commercial seeding mix was deposited into 128-cell seedling plug trays or standard trays for soil-drench assays. Trays were then held on greenhouse benches under standard environmental conditions of temperature and lighting. Fungal strains were cultured on agar medium (potato dextrose agar, torula yeast agar, corn meal agar) and incubated in preparation for spore/conidia production and harvesting. Culture plates were aseptically harvested by flooding with sterile, distilled water, then filtered through cheesecloth and diluted to desired conidial concentrations for inoculation. At the 1–2 true leaf stage, seedlings in each cell were inoculated with a conidial suspension of each test strain by spraying until run-off. Each cell was shielded individually to prevent cross-contamination. At least 2 cells (4 seedlings) per strain were utilized. After inoculation, seedlings were exposed to simulated dew for a minimum of 8 hours at 28 ºC, then returned to greenhouse benches. Overall efficacy of control was scored for each isolate on a 0–5 scale where 0 = no disease development and 5 = plant mortality. For soil drench assays, mycelial fragments were collected in sterile water by scraping potato dextrose agar cultures of 10–20 distinct biological control candidates per experiment (3 Petri plates per isolate; 5 mL of sterile water per plate). Mycelial fragments were pooled (approximately 150 mL) and diluted to a final volume of 500 mL. Greenhouse trays (25 × 50 cm) were delineated into three sections (inoculated, mock-inoculated, and uninoculated). Trays were filled with commercial potting soil, and each of the three sections was sown with a row of Palmer pigweed seeds (105 seeds/row). Then, the pooled mycelia described above were used as the inoculum for one row per tray; sterile water was the mock inoculum in a separate row. For each experiment, at least three trays were utilized as described above per mycelial cocktail to provide experimental replication. For each tray, the lethality of the pooled mycelial fragments was scored as the percent of dead seedlings in the inoculated row compared to the mock-inoculated row. Putative fungal pathogens were re-isolated from diseased pigweed material and identified as described above.

Genetically tagged, insertional mutants of promising biological control strains were created using protoplast-mediated and agrobacterium-mediated transformation. For protoplast-mediated transformation, a mutagenesis cassette conveying a selectable marker (resistance to hygromycin B) and a screenable marker (constitutive expression of GFP) were amplified via a polymerase chain reaction. Protoplasts were produced and transformed according to the protocol described by Ridenour et al. (2012). For agrobacterium-mediated transformation, the construct pBHT2-sGFP transformed in the vector Agrobacterium tumefaciens strain AGL1 was used following the protocol of Li et al. (2013).

Mutants of potential biocontrol strains were screened on Palmer pigweed seedlings, which were grown and inoculated as described above. Wild-type strains were used as controls for comparison. A randomized complete block design was utilized, and treatment means were analyzed with a two-sample t-test ($P < 0.05$) to categorize strains. Strains were grouped into three categories as follows: increased, decreased, and unchanged aggressiveness compared to previous data and control strains (non-optimized wild type strains). Mutant strains with increased virulence were selected for further genetic analysis, as described below.

Results and Discussion

To date, over 200 unique isolates of fungal pathogens have been obtained and cataloged from Palmer pigweed in Arkansas. These isolates represent a broad range of fungal taxa and display substantial morphological diversity (Fig. 2). From this collection, nearly 200 isolates have been evaluated in greenhouse assays so that virulence on Palmer pigweed could be scored quantitatively. Thus far, one of the most promising strains is the isolate NC-3 of *Colletotrichum fioriniae* (Table 1). This isolate is virulent on pigweed but does not cause disease on soybean. This result is promising because C*olletotrichum* is a group of fungi that have historically provided some of the best candidates for biological control of agricultural weeds (Charudattan, 2001).

In a complementary approach, 10 'cocktail' mixtures of Palmer pigweed pathogens were inoculated into the soil as a soil drench assay at planting. Of the 10 pathogen cocktails tested, 9 induced less than 5% lethality, and 6 of the 9 cocktails induced 0% lethality. One cocktail, however, killed pigweed seedlings at nearly 100% efficacy. From this cocktail, 36 fungal isolates were re-isolated from dead pigweed seedlings. All of the pathogenic isolates were determined to be members of the fungal genus *Colletotrichum*, and the majority of these were redundant isolations of a single pathogenic strain (PWA78). This strain was subsequently evaluated on pigweed plants with soil, stem, and foliar inoculations in the greenhouse. Lethality of strain PWA78 on seedlings was confirmed, and the strain was also observed to be virulent on stem and leaf tissues.

Mutagenesis experiments and secondary greenhouse screens are ongoing. *Colletotrichum* species are easy to genetically transform, which means that large numbers of mutants can be created quickly and cheaply. Greenhouse screens of mutants require considerable replication and thus are somewhat laborious, yet are feasible due to the rapid growth rate of Palmer pigweed and a focus on killing juvenile plants before they produce seed. Bioinformatic pipelines for gene discovery have been created in advance so that genes associated with increased virulence in interesting mutants can be identified quickly and cheaply.

Practical Applications

The sustainable and affordable control of Palmer pigweed is crucial for soybean producers in Arkansas and beyond to maintain profitability. Current management approaches that rely heavily on chemical herbicides have serious weaknesses due to the demonstrated ability of Palmer pigweed to repeatedly develop a genetic resistance to diverse herbicides. The creation and commercialization of a bioherbicide targeted specifically for Palmer pigweed will provide soybean growers a powerful new management tool that can be used in conjunction with existing integrated pest management programs for pigweed control.

Acknowledgments

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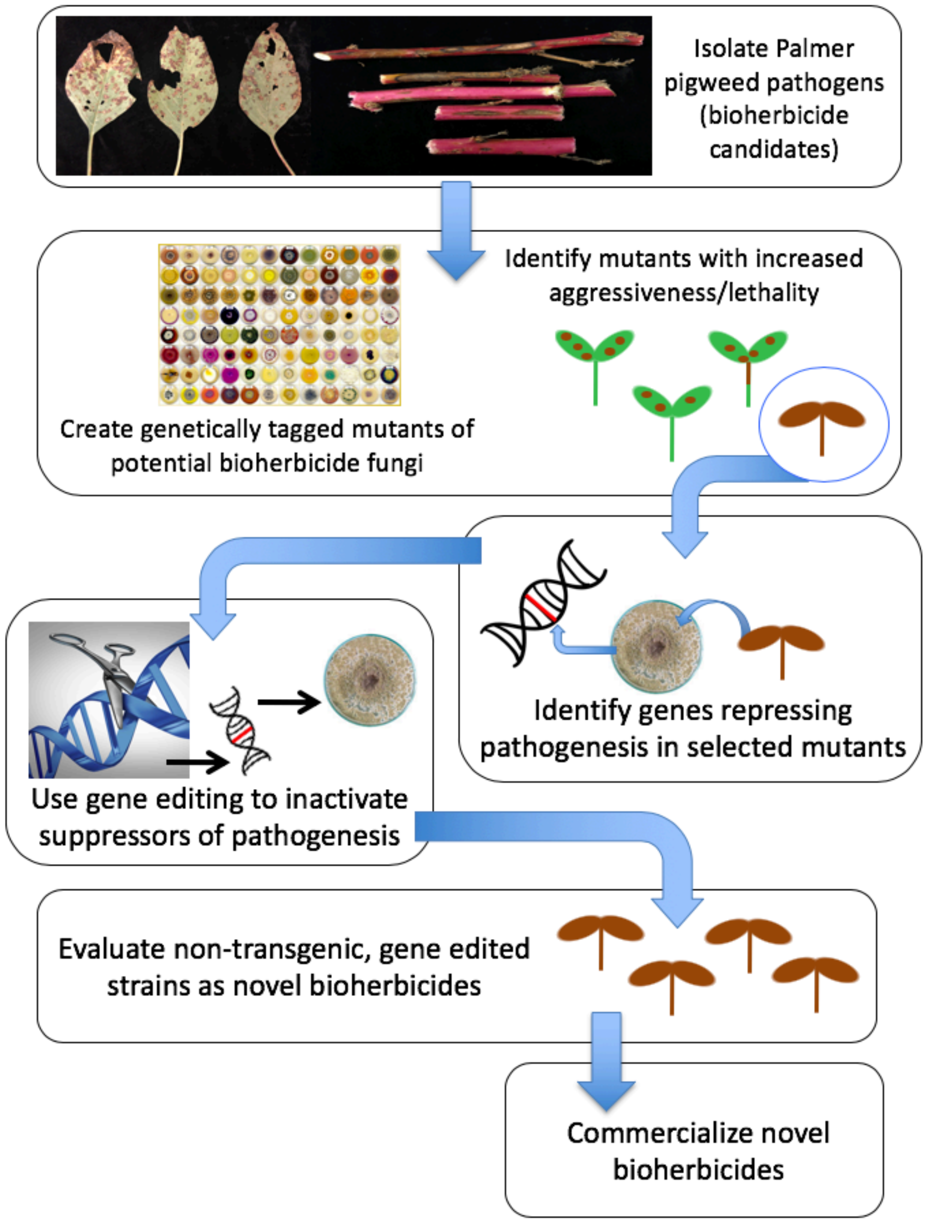

Fig. 1. Schematic overview of the process to create novel bioherbicides. Step 1: Isolate Palmer pigweed pathogens. Step 2: Mutagenize pathogens and identify mutants with increased aggressiveness/lethality. Step 3: Identify genes repressing pathogenesis. Step 4: Inactivate pathogenesis suppressors via gene editing. Step 5: Evaluate pathogenesis of non-transgenic, gene edited strains. Step 6: Commercialize novel bioherbicides.

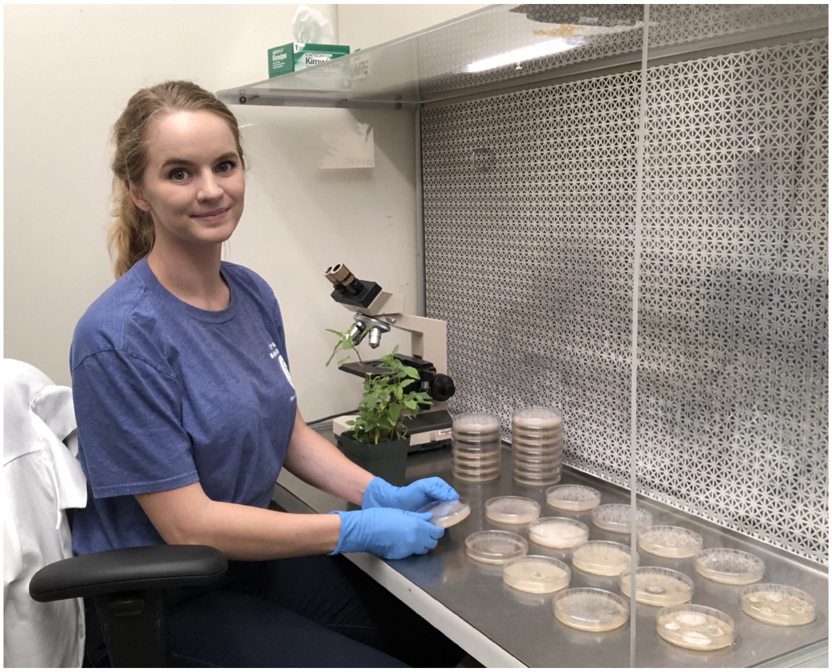

Fig. 2. Isolates of fungal pathogens from Palmer pigweed were first identified by culture and spore morphology. Over 200 taxonomically diverse isolates were collected from 2016 to the present.

Table 1. Example of results from a greenhouse irulence screen of potential Palmer pigweed bioherbicide candidates.

		Disease rating[a]	
Strain name	**Taxonomic identification**	**Palmer pigweed**	**Soybean**
Ct-1	*Colletotrichum truncatum*	1	0
M3	*Colletotrichum truncatum*	1	0
M4	*Colletotrichum truncatum*	2	0
M5	*Colletotrichum truncatum*	1	0
NC-3	*Colletotrichum fioriniae*	4	0
None	Negative control (water)	0	0

[a] The disease rating scale was categorical, ranging from 0 (no disease) to 5 (lethality).

Soybean Cultivar Sensitivity to Benzobicyclon and Other Rice Herbicides

J.A. Patterson,[1] J.K. Norsworthy,[1] R.B. Farr,[1] and O.W. France[1]

Abstract

Gowan Company® is currently pursuing registration of benzobicyclon, a Group 27 herbicide, as a post-flood herbicide option in rice. It will be the first 4-hydroxyphenylpyruvate dioxygenase-inhibiting herbicide commercially available in mid-South rice production. Benzobicyclon is a pro-herbicide; therefore it must undergo a non-enzymatic hydrolytic reaction to be converted to the potent and phytotoxic compound benzobicyclon hydrolysate. For this hydrolytic reaction to occur and for benzobicyclon hydrolysate to be formed, water must be present. Therefore, benzobicyclon must be applied post-flood. Because benzobicyclon must be applied post-flood, applications will be made aerially. As a result, the risks associated with the off-target movement of the herbicide onto adjacent soybean fields must be evaluated and understood. In 2018 and 2019, field experiments were conducted at the University of Arkansas System Division of Agriculture's Milo J. Shult Agricultural Research and Extension Center in Fayetteville, Ark. to evaluate the impact of low rates of benzobicyclon and other rice herbicides on sulfonylurea-tolerant soybean (STS) and non-STS soybean when applied at the R1 growth stage. The experiments were implemented as randomized complete block designs with a split-plot treatment structure. Low rates (1/180x, 1/60x, and 1/20x) of benzobicyclon (Rogue®), halosulfuron (Permit®), benzobicyclon + halosulfuron (Rogue Plus®), penoxsulam (Grasp®), bispyribac-sodium (Regiment®), and florpyrauxifen-benzyl (Loyant®) were made on STS and non-STS soybean. In both years, at 14 days after treatment (DAT), when the 1/20x rate was applied, Grasp, Regiment, and Loyant severely injured both soybean cultivars at levels ranging from 65% to 80%. Conversely, in both years, treatments containing the 1/20x rate of benzobicyclon or benzobicyclon plus halosulfuron were much less injurious to soybean at levels ≤ 20%. These findings indicate that benzobicyclon can be safely applied by airplane with minimal risk of off-target injury on adjacent soybean.

Introduction

Weedy rice (*Oryza sativa* L.) is the third-most problematic weed in mid-South rice production behind barnyardgrass [*Echinochloa crus-galli* (L.) P. Beauv.] and sprangletop (*Diplachne* spp.) (Norsworthy et al., 2013). Postemergence options for controlling weedy rice are limited because weedy rice is the same species as cultivated rice, making it difficult to control without also damaging the crop (Burgos et al., 2014). Gowan Company® is currently pursuing registration of benzobicyclon, a Group 27 herbicide that inhibits 4-hydroxyphenylpyruvate dioxygenase (HPPD). The herbicide will be marketed as a post-flood option to control mid-South rice weeds, including weedy rice. Benzobicyclon is a pro-herbicide, therefore it does not directly inhibit HPPD enzymes in plants (Komatsubara et al., 2009). Rather, benzobicyclon must undergo a non-enzymatic hydrolytic reaction to be converted to the potent and phytotoxic compound benzobicyclon hydrolysate. Because benzobicyclon requires the presence of water to be phytoactive, it must be applied post-flood. The rapid evolution of resistance to many commonly applied rice herbicides has forced Midsouth rice producers to implement new herbicide options for rice weed control. Some of the new rice weed control options include the use of acetolactate synthase (ALS)-inhibiting, HPPD-inhibiting, and synthetic auxin herbicides. Developed by DuPont®, sulfonylurea-tolerant soybean (STS) technology was commercialized to allow soybean producers to apply ALS-inhibiting chemistries mid-season in their soybean crop without also eliciting damage to the crop (Albrecht et al., 2017). The STS soybean cultivars may provide additional options for weed control, but other sites-of-action are commonly used due to many problematic weeds in soybean being resistant to ALS-inhibiting herbicides. As a result, a majority of mid-South soybean acres are planted with non-STS cultivars, which renders them susceptible to the ALS-inhibiting herbicides that are being applied to rice fields. In addition to being susceptible to ALS-inhibiting herbicides, non-STS soybean cultivars are also susceptible to HPPD-inhibiting and synthetic auxin herbicides. Therefore, research must be conducted to evaluate and understand the

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risks associated with the off-target movement of benzobicyclon relative to other commonly applied rice herbicides onto adjacent soybean fields.

Procedures

In the summer of 2018 and 2019, field experiments were conducted at the University of Arkansas System Division of Agriculture's Milo J. Shult Agricultural Research and Extension Center in Fayetteville, to evaluate the impact of low rates of benzobicyclon and other commonly applied rice herbicides on STS and non-STS soybean when applied at the R1 growth stage. The experiments were implemented as randomized complete block designs with split-plot treatment structures with the whole plot factors being herbicide by rate and the subplot factor being soybean cultivar. Each treatment was replicated four times in each experiment. In each four-row plot, two rows of P47T76 (non-STS) and DGSTS47 (STS) were planted adjacently at a 1-in. depth at a seeding rate of 140,000 seeds/ac. Only the center two rows, one containing STS soybean and the other containing non-STS soybean, received the herbicide application, allowing for running checks on each side of the plot. Therefore, each experimental plot measured 3-ft by 20-ft. A broadcast burndown application of glyphosate (RoundUp® PowerMax®) and paraquat (Gramoxone®) were made, followed by a preemergence application of sulfentrazone + *S*-metolachlor (BroadAxe®) to ensure the experiments were weed-free. Additional herbicide applications and mechanical weeding were used as needed throughout the growing season to control any subsequently emerged weeds. Six herbicides were used in the experiments, and each herbicide was applied at a 1/180X, 1/60X, and 1/20X rate. The herbicides included: benzobicyclon (Rogue®), benzobicyclon + halosulfuron (Rogue Plus®), halosulfuron (Permit®), penoxsulam (Grasp®), bispyribac-sodium (Regiment®), and florpyrauxifen-benzyl (Loyant®). The herbicide treatment combinations evaluated in the experiments are listed in Table 1. All herbicide applications for the evaluated treatments were made with a CO_2-pressurized backpack sprayer using a handheld four-nozzle boom equipped with 110015 AIXR nozzles calibrated to deliver 15 gallons per acre (GPA) at 40 Psi. When applying the herbicide treatments, spray shields were used on the outside of the center two rows to mitigate the physical drift of spray particles onto the running checks.

Data collection consisted of visible estimations of crop injury and yield. Visible estimations of crop injury were collected at 14 days after application. Because of herbicide tolerance differences between the two soybean cultivars, they were rated for crop injury separately. Ratings were based on a scale of 0% to 100%, with 0% being no visible crop injury and 100% being complete plant death. Each experimental plot was machine harvested using a small-plot combine to determine yield roughly two weeks after reaching R8 maturity. Data were analyzed using JMP Pro 15.1 and were subjected to analysis of variance, and site years were analyzed separately due to site year having a significant main effect. All means were separated using Fisher's protected least significant difference test ($\alpha = 0.05$).

Results and Discussion

In 2018, 14 days after treatment (DAT), there was a significant interaction of herbicide and rate for visible estimations of crop injury ($P < 0.0001$). When applied at the 1/20x rate, Grasp, Regiment, and Loyant severely injured both soybean cultivars at levels ranging from 64% to 78% (Table 2). When applied at the 1/60x or 1/180x rate, Loyant was very injurious to both soybean cultivars at 56% and 41%, respectively (Table 2). All other herbicide treatments, regardless of rate, were less injurious to both soybean cultivars at levels ≤ 23% (Table 2). In 2018, there was a significant interaction of herbicide and soybean cultivar for yield ($P > 0.0498$). Regardless of the rate, all herbicide treatments, except for Permit, exacerbated a decrease in yield when compared to the non-treated control (Table 3). In 2019, 14 days after treatment (DAT), there was a significant interaction of herbicide and rate for visible crop injury ($P < 0.0001$). Similar to data collected in 2018, in 2019, when applied at the 1/20x rate, Grasp, Regiment, and Loyant severely injured both soybean cultivars at levels ranging from 62% to 79% (Table 4). When applied at the 1/60x rate, Grasp, Regiment, and Loyant were injurious to both soybean cultivars at levels upwards of 43%, 44%, and 60%, respectively (Table 4). Yield data were not collected in 2019 because plots were mowed late in the season by an employee at the Milo J. Shult Agricultural Research and Extension Center. Overall, benzobicyclon-containing treatments were much less injurious to both soybean cultivars than other treatments. Additionally, benzobicyclon-, benzobicyclon plus halosulfuron-, and Permit-containing treatments provided greater crop safety than Grasp-, Regiment-, and Loyant-containing treatments.

Practical Applications

Findings from this research indicate that benzobicyclon can be safely applied with minimal risk of off-target crop injury on adjacent soybean. Also, a continuous flood is required for benzobicyclon to be phytoactive; therefore it is unlikely to injure actively growing soybean. Therefore, the use of benzobicyclon in mid-South rice production systems could be a viable rice weed control option while also providing safety against off-target crop injury on soybean, but additional years of research are needed to validate this conclusion.

Acknowledgments

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Table 1. List of herbicide treatments for 2018 and 2019 soybean sensitivity to benzobicyclon experiments at the Milo J. Shult Agricultural Research and Extension Center in Fayetteville, Arkansas.

Treatment Number	Herbicide Treatment†	Diluted Rate	Rate
			fl oz/ac
1	Non-treated	--	--
2	Rogue® (benzobicyclon) + COC	1/180X	0.0467
3	Rogue (benzobicyclon) + COC	1/60x	0.1458
4	Rogue (benzobicyclon) + COC	1/20X	0.42
5	Rogue Plus® (benzobicyclon + halosulfuron) + COC	1/180X	0.0296
6	Rogue Plus (benzobicyclon + halosulfuron) + COC	1/60X	0.0889
7	Rogue Plus (benzobicyclon + halosulfuron) + COC	1/20X	0.2667
8	Permit® (halosulfuron) + COC	1/180X	0.0037
9	Permit (halosulfuron) + COC	1/60x	0.01111
10	Permit (halosulfuron) + COC	1/20X	0.0333
11	Grasp® (penoxsulam) + MSO	1/180X	0.0156
12	Grasp (penoxsulam) + MSO	1/60x	0.0467
13	Grasp (penoxsulam) + MSO	1/20X	0.14
14	Regiment® (bispyribac-sodium) + Dyne-A-Pak	1/180X	0.0037
15	Regiment (bispyribac-sodium) + Dyne-A-Pak	1/60x	0.0112
16	Regiment (bispyribac-sodium) + Dyne-A-Pak	1/20X	0.0335
17	Loyant® (florpyrauxifen-benzyl) + MSO	1/180X	0.0889
18	Loyant (florpyrauxifen-benzyl) + MSO	1/60x	0.2667
19	Loyant (florpyrauxifen-benzyl) + MSO	1/20X	0.8

† Treatment abbreviations: COC = crop oil concentrate at 1% v/v; MSO = methylated seed oil at 1% v/v; Dyne-A-Pak = non-ionic surfactant blend at 2.5% v/v.

Table 2. Significant interaction of herbicide and rate on visible crop injury averaged across soybean cultivar 14 days after treatment for the 2018 experiment at the Milo J. Shult Agricultural Research and Extension Center in Fayetteville, Arkansas.

	Visible Injury 14 DAT‡		
Herbicide Treatment†	1/20x	1/60x	1/180x
	--------------------%--------------------		
Benzobicyclon + COC	3 h§	3 h	13 f
Benzobicyclon + halosulfuron + COC	11 fg	2 h	1 h
Permit® (halosulfuron) + COC	4 h	2 h	1 h
Grasp® (penoxsulam) + MSO	64 b	6 fgh	1 h
Regiment® (bispyribac-sodium) + Dyne-A-Pak	66 b	23 e	5 gh
Loyant® (florpyrauxifen-benzyl) + MSO	78 a	56 c	41 d

† Treatment abbreviations: COC = crop oil concentrate at 1% v/v; MSO = methylated seed oil at 1% v/v; Dyne-A-Pak = non-ionic surfactant blend at 2.5% v/v.

‡ Days after treatment (DAT).

§ Letters are used to separate means. Data with the same letters are not significantly different.

Table 3. Significant interaction of herbicide and soybean cultivar on yield averaged across herbicide rates for the 2018 experiment at the Milo J. Shult Agricultural Research and Extension Center in Fayetteville, Arkansas.

Herbicide Treatment†	Yield	
	Non-STS‡	STS
	bu./ac	bu/ac
Non-treated	35	33
Benzobicyclon + COC	29 abcd§	23 cde
Benzobicyclon + halosulfuron + COC	32 ab	30 abc
Permit® (halosulfuron) + COC	36 a	32 ab
Grasp® (penoxsulam) + MSO	31 abc	30 abc
Regiment® (bispyribac-sodium) + Dyne-A-Pak	32 ab	23 de
Loyant® (florpyrauxifen-benzyl) + MSO	20 e	27 bcde

†Treatment Abbreviations: COC = crop oil concentrate at 1% v/v; MSO = methylated seed oil at 1% v/v; Dyne-A-Pak = non-ionic surfactant blend at 2.5% v/v.

‡ STS = sulfonylurea-tolerant soybean.

§ Letters are used to separate means. Data with the same letters are not significantly different.

Table 4. Significant interaction of herbicide and rate on visible crop injury averaged across soybean cultivar 14 days after treatment for the 2019 experiment at the Milo J. Shult Agricultural Research and Extension Center in Fayetteville, Arkansas.

Herbicide Treatment†	Visible Injury 14 DAT‡		
	1/20x	1/60x	1/180x
		%	
Rogue® (benzobicyclon) + COC	0 i§	0 i	3 hi
Rogue Plus® (benzobicyclon + halosulfuron) + COC	23 e	11 g	4 hi
Permit® (halosulfuron) + COC	17 f	10 g	4 hi
Grasp® (penoxsulam) + MSO	71 b	43 d	46 d
Regiment® (bispyribac-sodium) + Dyne-A-Pak	62 c	44 d	7 gh
Loyant® (florpyrauxifen-benzyl) + MSO	79 a	60 c	48 d

†Treatment abbreviations: COC = crop oil concentrate at 1% v/v; MSO = methylated seed oil at 1% v/v; Dyne-A-Pak = non-ionic surfactant blend at 2.5% v/v.

‡ Days after treatment = DAT.

§ Letters are used to separate means. Data with the same letters are not significantly different.

Economic Analysis of the 2019 Arkansas Soybean Research Verification Program

C.R. Stark, Jr.

Abstract

Economic and agronomic results of a statewide soybean research verification program can be a useful tool for producers making production management decisions prior to and within a crop growing season. The 2019 results provide additional economic relationship insights among seasonal, herbicide, and irrigation production systems, especially concerning full- versus late-season crops. Full-season production system fields had approximately 12.5 bu./ac higher yields and $137 per acre higher net returns than Late-season system fields. Roundup Ready© (RR) herbicide production system fields had a 6 bushel per acre yield advantage over LibertyLink© (LL) system fields and a $50 per acre advantage in net returns across all program fields. But under furrow irrigation, the LL systems yielded 2.5 bushels more per acre with $14.50 more net returns than RR fields. Irrigated systems were far superior to non-irrigated systems based on both yields and net returns. Lower total cost levels of $80 per acre associated with non-irrigated system fields could not overcome yield and associated revenue disadvantages.

Introduction

The Arkansas Soybean Research Verification Program (SRVP) originated in 1983 with a University of Arkansas System Division of Agriculture's Cooperative Extension Service (CES) study consisting of four irrigated soybean fields. Records have been compiled each succeeding year from the fields of participating cooperators until over 500 individual fields now comprise the state data set. Among other goals, the program seeks to validate CES standard soybean production recommendations and demonstrate their benefits to state soybean producers. Annual SRVP reports have shown that the average soybean grain yields of participating fields are consistently exceeding the state average soybean yields, even as both measures have trended upward (Stark et al., 2008). Specific production practice trends have also been identified using the SRVP database, such as herbicide use rates (Stark et al., 2011). Cooperating producers in each yearly cohort are identified by their County Extension Agent. Each producer receives timely management guidance from state SRVP coordinators regularly and from CES specialists as needed. Economic analysis has been the primary focus of the program from the start.

The SRVP coordinators record input rates and production practices throughout the growing season, including official yield measures at harvest. A State Extension Economist compiles the data into the spreadsheet used for the annual cost of production budget development. Measures of profitability and production efficiency are calculated for each cooperator's field and grouped by the soybean production system.

Procedures

Twenty cooperating soybean producers from across Arkansas provided input quantities and production practices utilized during the 2019 growing season.

A state average soybean market price was estimated by compiling daily forward booking and cash market prices for the 2019 soybean crop. The collection period was 1 Jan. through 31 Oct. 2019 for the weekly soybean market report published on the Arkansas Row Crops Blog (Stark, 2019). Data was entered into the 2019 Arkansas Soybean Enterprise Budgets for each respective production system (Watkins, 2019). Input prices and production practice charges were primarily estimated by the budget values. Missing values were estimated using a combination of industry representative quotes and values taken from the Mississippi State Budget Generator program for 2019 (Laughlin and Spurlock). Summary reports, by field, were generated and compiled to generate production system results.

Results and Discussion

The twenty fields included in the 2019 Arkansas Soybean Research Verification Program report (Elkins, 2019) spanned 11 different production systems based on combinations of seasonal, herbicide, and irrigation characteristics (Table 1). The system combination that utilizes a full-season, Roundup Ready© (RR) technology seed, and furrow irrigation was most common with five fields. Four fields were Late-season, LibertyLink© (LL) seed, and furrow irrigation. The full-sea-

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son, LibertyLink© (LL) seed, and furrow irrigation system and the late-season, Roundup Ready© (RR) technology seed, and furrow irrigation system combinations were found on two fields each. The remaining seven combinations, respectfully, each occurred on only one field. All economic comparisons were developed from soybean forward book and cash market prices for the 2019 crop reported by Stark in weekly and monthly summary market reports (Stark, 2019). The soybean forward book and cash market price for the 2019 crop averaged $8.74/bu. throughout 1 Jan.–31 Oct. 2019. Market price multiplied by yield gave field revenues. No grade reductions or premiums were included. All yields were standardized to 13% moisture content. Readers should note that the small number of fields in total and numbers within groups of fields represented in this study do not permit standard statistical analysis. Yield and economic results are presented by grouping only for discussion purposes. Economic comparisons are drawn across seasonal, herbicide, and irrigation characteristics (Tables 2, 3, and 4). The values for yield, revenue, total variable cost, total fixed cost, total cost, and return to land and management are discussed.

Season Comparisons. The rainfall and flooding weather combination for early 2019 made early-season production system fields impossible to establish for the cooperating producers in the program. All twenty fields were classified as either full-season or late-season systems. Early planting was still validated as the nine full season fields had over 12.5 bu./ac higher average yields than the eleven late-season fields (Table 2). Revenue was $108/ac higher, and both variable and fixed costs were lower than the corresponding costs on late-season fields. Returns to land and management were over $137/ac higher on full-season fields. These economic results are consistent with and support CES recommendations for early systems in Arkansas.

Herbicide Comparisons. Roundup Ready© (RR) and LibertyLink© (LL) herbicide systems were approximately equal with ten RR and nine LL fields (Table 3). One field had a conventional, non-transgenic seed. Yield comparisons by herbicide showed the RR fields had a 6 bu./ac advantage over LL in 2019. This result was similar to 2018 and contradicted 2017 data where yields were essentially the same. RR fields in 2019 were $8/ac less expensive in variable costs, but $10/ac higher in fixed costs than LL fields. The total cost per acre difference was less than $2/ac. Returns to land and management gave a $50/ac advantage to Roundup Ready herbicide fields.

Irrigation Comparisons. The heavy spring precipitation in 2019 might have suggested that non-irrigated fields would have ample moisture and produce equivalent yields at a lower cost compared to irrigated fields. Recorded yields on the two non-irrigated fields instead were less than half of the irrigated yields. The $80/ac total cost savings were more than offset by the yield reduction resulting in losses for both non-irrigated producers. Irrigation systems employed by growers in the 2019 program were predominantly furrow (15 fields) with one center pivot field and two flood systems (Table 4). The eighteen irrigated fields averaged 58.6 bu./ac compared to 24.8 bu./ac for the two non-irrigated fields. Revenue was almost $300 higher per acre for irrigated fields, but substantial cost differences were again seen for irrigated versus non-irrigated. Total variable costs averaged $259.84/ac overall irrigated fields compared to $200.11 on non-irrigated. Total fixed costs differed similarly with irrigated fields at $88.71/ac and non-irrigated averaging $61.81/ac. The combination of costs left irrigated fields at an average Total Cost of $348.55/ac compared to $261.92/ac for non-irrigated. Returns to land and management averaged $208.39 higher per acre for irrigated fields over non-irrigated.

Overall Comparisons. The 2019 Arkansas Soybean Research Verification Program fields had a 55.2 bu./ac statewide average yield, 7.6 bushels less than 2018. Revenue averaged $482.27/ac generated from this production, a decline of over $96/ac from 2018. Total variable costs averaged $253.86, a $2 decline, and total fixed costs averaged $86.02, less than $1 lower, for an average total cost per acre of $339.89, slightly over $2.50 lower compared to the 2018 economic analysis. These revenue and cost averages left producers with an average per acre Returns to land and management of $142.39 across all production systems, a decline per acre of over $94 compared to 2018.

Practical Applications

The results of state Soybean Research Verification Programs can provide valuable information to producers statewide. Illustration of the returns generated when optimum management practices are applied can facilitate the distribution of new techniques and validate the standard recommendations held by state row crop production specialists. Adoption of these practices can benefit producers currently growing soybeans and those contemplating production.

Acknowledgments

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Table 1. Soybean Research Verification program production system combinations, 2019.

Season[a]	Full	Late	Full	Late	Late	Full	Late	Full	Late	Late	Late
Herbicide[b]	RR	RR	RREx	RREx	LL	LL	LL	LL	LL	RR	CON
Irrigation[c]	Fur	Fur	Fur	Fur	CP	Dry	Dry	Fur	Fur	FL	FL
# Fields	5	2	1	1	1	1	1	2	4	1	1

[a] Production Systems: Full = Full Season; Late = Late Season.
[b] RR = Roundup Ready; RREx = Roundup Ready Extend; LL = Liberty Link; CON = Conventional.
[c] Furrow = Furrow Irrigation; Dry = Non-Irrigated; CP = Center Pivot Irrigation; FL = Flood Irrigation.

Table 2. Soybean Research Verification program economic results by seasonal system, 2019

Seasonal Production System	Full-season	Late-season
# Fields	9	11
Yield (bu./ac)	62.0	49.6
Revenue ($)	541.59	433.74
Total Variable Costs ($)	242.25	263.37
Total Fixed Costs ($)	81.45	89.76
Total Costs ($)	323.70	353.13
Returns to Land and Management ($)	217.89	80.61

Source: *2019 Arkansas Soybean Research Verification Program Report.*

Table 3. Soybean Research Verification program economic results by herbicide system, 2019.

Herbicide Production System	Roundup Ready®	Roundup Ready Xtend®	Liberty Link™	Conventional
# Fields	8	2	9	1
Yield (bu./ac)	56.5	65.2	52.2	48.9
Revenue ($)	493.37	569.41	456.62	427.39
Total Variable Costs ($)	251.95	240.04	257.48	269.97
Total Fixed Costs ($)	93.96	81.20	81.21	84.98
Total Costs ($)	345.91	321.23	338.69	354.96
Returns to Land and Management ($)	147.47	248.18	117.93	72.43

Source: *2019 Arkansas Soybean Research Verification Program Report.*

Table 4. Soybean Research Verification program economic results by irrigation system, 2019.

Irrigation Production System	Irrigated	Non-Irrigated
# Fields	18	2
Yields (bu./ac)	58.6	24.8
Revenue ($)	511.78	216.76
Total Variable Costs ($)	259.84	200.11
Total Fixed Costs ($)	88.71	61.81
Total Costs ($)	348.55	261.92
Returns to Land and Management ($)	163.22	-45.17

Source: *2019 Arkansas Soybean Research Verification Program Report.*

2019 Soybean Enterprise Budgets and Production Economic Analysis

B. J. Watkins[1]

Abstract

Crop enterprise budgets are developed that are flexible for representing alternative production practices of Arkansas producers. Interactive budget programs apply methods that are consistent overall field crops. Production practices for base budgets represent the University of Arkansas System Division of Agriculture, Cooperative Extension Services' recommendations from Crop Specialists, and the Soybean Research Verification Program (SRVP). Unique budgets can be customized by users based on either Extension recommendations or information from producers for their production practices. The budget program is utilized to conduct an economic analysis of field data in the SRVP. The crop enterprise budgets are designed to evaluate the solvency of various field activities associated with crop production. Costs and returns analysis with budgets are extended by production economics analysis to investigate factors impacting farm profitability.

Introduction

The availability of new technologies for soybean producers provides interesting and unique opportunities for producers across Arkansas. Coupled with low commodity prices and rising input costs, evaluating production methods has become crucial for producer's financial stability. The objective of crop enterprise budgets is to develop an interactive computational program, which allows stakeholders of the soybean industry to evaluate numerous production methods for comparative costs and returns dependent upon a wide range of inputs.

Procedures

Crop enterprise budgets are developed based upon input from crop specialists across the state. Input prices are gathered directly from suppliers to create cost estimates unique to the production year. Input costs for fertilizers and chemicals are estimated by applying prices to typical input rates based upon crop specialists' recommendations. Equipment prices, custom hire rates, and fees are estimated with information from those within the agricultural industry in Arkansas. Methods of estimating these operating expenses presented in crop enterprise budgets are identical to producers obtaining costs information for their specific farms.

Ownership costs and repair expenses for machinery are estimated by applying engineering formulas to representative prices of new equipment (Givan, 1991; Lazarus and Selly, 2002). Repair expenses in crop enterprise budgets should be regarded as value estimates of full-service repairs. Repairs and maintenance performed by hired farm labor will be partially realized as wages paid to employees. Machinery performance rates of field activities utilized for machinery costs are used to estimate time requirements of an activity which is applied to an hourly wage rate for determining labor costs (USDA-NASS, 2018). Labor costs in the crop enterprise budgets represent time devoted to specified field activities listed at the beginning of each budget.

Ownership costs of machinery are determined by the capital recovery method, which determines the amount of money that should be set aside each year to replace the value of equipment used in production (Kay and Edwards, 1999). One should note this measure differs from typical depreciation methods, as well as actual cash expenses for machinery. Amortization factors applied for capital recovery estimation coincide with prevailing long-term interest rates (Edwards, 2005). Interest rates in this report are from Arkansas lenders, as reported in October 2018. Representative prices for machinery and equipment are based on contacts with Arkansas dealers and industry list prices (Deere & Company, 2018; MSU, 2018). Revenue in the crop enterprise budgets is the product of expected yields from following the University of Arkansas System Division of Agriculture's Cooperative Extension Service's (CES) research verification practices and average commodity prices over the month the budgets are created.

Results and Discussion

The Department of Agricultural Economics and Agribusiness (AEAB) and Agriculture and Natural Resources

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(ANR) of the University of Arkansas System Division of Agriculture, together, develop annual crop enterprise budgets to assist Arkansas producers and other agricultural stakeholders in evaluating expected costs and returns for the upcoming field crop production year. Production methods analyzed represent typical field activities as determined by consultations with farmers, CES County Agents, and information from CES' Row Crop Research Verification Program coordinators in the Department of Crop, Soil, and Environmental Sciences. Actual production practices vary greatly among individual farms due to management preferences. Analyses are for generalized circumstances with a focus on the consistent and coordinated application of budget methods for all field crops. This approach results in meaningful costs and returns comparisons for decision making related to acreage allocations among field crops. Results should be regarded only as a guide and basis as individual farmers should develop budgets for their production practices, soil texture, and other unique circumstances within the budget tool to represent each unique operation more accurately.

Table 1 presents a summary of estimated 2019 costs and returns for Arkansas furrow irrigated soybeans utilizing field activities associated with a Roundup Ready® production system. Costs are presented on a per-acre basis and with an assumed 1000 acres. Program flexibility allows users to change total acres, as well as other variables, to represent unique farm situations. Returns to total specified expenses are $152.13/ac. The budget program includes similar capabilities for center pivot irrigated and non-irrigated soybean production for Roundup Ready®, Roundup Ready® 2 Xtend, LibertyLink®, LibertyLink GT27™, Enlist E3™, and conventional varieties.

Crop insurance information in Table 1 associates input costs with alternative coverage levels for insurance. For example, with an actual production history yield (APH) yield of 54.0 bu./ac and an assumed projected price of $8.00/bu., input costs could be insured at selected coverage levels greater than 51%. Production expenses represent what is commonly termed as "out-of-pocket costs" and could be insured at coverage levels greater than 59%. Total specified expenses could be insured at coverage levels of 79%.

Practical Applications

The benefits provided by the economic analysis of alternative soybean production methods provide a significant reduction in financial risk faced by producers. Arkansas producers have the capability with the budget program to develop economic analyses of their production activities. Unique crop enterprise budgets developed for individual farms are useful for determining credit requirements and for planning production methods with the greatest potential for financial success. Flexible budgets enable farm financial outlooks to be revised during the production season as inputs, input prices, yields, and commodity prices change. Incorporating changing information and circumstances into budget analysis assists producers and lenders in making decisions that manage financial risks inherent in agricultural production.

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Table 1. 2019 Summary of revenue and expenses, furrow irrigated soybeans, per acre and 1,000 acres.

Summary of Revenue and Expenses			Crop Insurance Information	
Revenue	**Per Acre**	**Farm**		**Per Acre**
Acres	1	1000	**Enter for Farm**	
Yield (bu.)	60.00	60,000	APH[a] Yield	54.0
Price ($/bu.)	9.40	9.40	Projected Price	8.00
Grower Share	100%	100%		
Total Crop Revenue	**564.00**	**564,000**	**Revenue**	**432.00**
Expenses				**Percent of Revenue**
Seed	64.29	64,286		11%
Fertilizers & Nutrients	34.68	34,680		7%
Chemicals	92.13	92,130		15%
Custom Applications	14.00	14,000		3%
Diesel Fuel, Field Activities	15.85	15,850		2%
Irrigation Energy Costs	31.18	31,182		6%
Other Inputs	3.88	3880		<1%
Input Costs	**254.14**	**254,136**		**45%**
Fees	7.00	7000		1%
Crop Insurance	7.21	7210		1%
Repairs & Maintenance, Includes Employee Labor	17.66	17,664		3%
Labor, Field Activities	10.57	10,565		2%
Production Expenses	**296.58**	**296,575**		**52%**
Interest	6.38	6376		1%
Post-harvest Expenses	19.02	19,020		3%
Custom Harvest	0.00	0		0%
Total Operating Expenses	**321.97**	**321,972**		
Returns to Operating Expenses	**242.03**	**242,028**		
Cash Land Rent	0.00	0		0%
Capital Recovery & Fixed Costs	89.89	89,894		17%
Total Specified Expenses	**411.87**	**411,866**		
Returns to Specified Expenses	**152.13**	**152,134**		
Operating Expenses/bu.	5.37	5.37		
Total Specified Expenses/bu.	6.86	6.86		

[a] APH = Actual production history.

Farm and Producer Factors Influencing the Use of Border Irrigation, Deep Tillage, and Warped Surface Leveling

K.F. Kovacs[1] and V.P. Bailey[1]

Abstract

A statistical model evaluated the farm and producer characteristics that influenced the use and the number of acres that use border irrigation, warped surface leveling, and deep tillage in Arkansas. The use of warped surface leveling increased by 10% if a producer has family or friends (i.e., peer network) that use on-farm reservoirs or flow meters. The use of deep tillage increased by 18% if a producer has a peer network that used computerized hole selection. Producers who grow soybean were 30% more likely to use warped surface leveling or deep tillage. Having a peer who used a tailwater recovery system increased the land in operation with deep tillage by more than 600 acres. Each additional acre of soybean on a farm operation increased the land in border irrigation by one-fifth of an acre and decreased the land in warped surface leveling by half an acre.

Introduction

We examined which factors, especially the use of irrigation practices by family and friends (i.e., peer networks), that influence Arkansas producers' use and the amount of irrigated land in border irrigation, warped surface leveling (i.e., grading where the crossgrade is not zero but adjusted with a computer to get the best fit), and deep tillage. Greater irrigation efficiency occurs through having crops utilize a greater proportion of the water applied to a field. Policymakers typically rely on voluntary programs to increase irrigation efficiency through cost-share of the installation costs for irrigation practices. Agricultural producers might accept a lower-cost share to use a new irrigation practice if producers already have a peer that successfully uses the irrigation practice. This would allow more producers to receive cost-share assistance since the overall level of taxpayer funds available in a given year is fixed. We supposed that a producer is in a peer network for an irrigation practice if they know a family member, friend, or neighbor who used the irrigation practice. The use of an irrigation practice and the relationship with the peer network could come about before or after a producer adopted an irrigation practice.

Arkansas' proportion of farmland with irrigation increased from 81% to 83% between 2013 and 2018. The state in the Lower Mississippi River Basin region with the next highest proportion of farmland irrigated is Mississippi, with only 67.1% of farmland that received irrigation (USDA, 2019). Arkansas is third in the United States, with only Texas and California being higher, according to the volume of water applied for irrigation at 5.1 million ac-ft. The average amount of water applied in Arkansas per acre in 2018 was 14 in. (USDA, 2019). More than 7.5% of the nearly 56 million acres of irrigated farmland in the United States in 2018 was in Arkansas (USDA, 2019). More than 90% of irrigated acres use gravity systems to distribute water to fields in Arkansas, and the remaining 10% of irrigated acres use sprinkler systems (USDA, 2019). About 18% of irrigated acres use precision leveling or zero-grading, and 14% of irrigated acres use tailwater pit, diking, time limits, or alternative row irrigation (USDA, 2019). Less than 4% of irrigated acres used shorter furrow lengths or other special furrow practices. A critical groundwater area has depths to groundwater of 66 ft to 150 ft according to the Arkansas Natural Resources Commission (ANRC), but groundwater levels rise the closer the aquifer is to the Mississippi River (ANRC, 2018).

We considered three types of efficient irrigation practices: 1) border irrigation, 2) warped surface leveling, and 3) deep tillage. The irrigation practices can aid in greater water delivery to the crops and less runoff (Schaible and Aillery, 2012). By identifying the factors that relate to the use of these practices, we gained insight into the process driving irrigation practice adoption that becomes more critical as groundwater levels fall. We examined the number of acres irrigated through these irrigation practices in conjunction with the decision to use each practice, to understand what motivates producers to expand the use of an irrigation practice.

Procedures

The dataset used for this study was obtained from the Arkansas Irrigation Use Survey conducted through collabora-

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tion with Mississippi State University and Louisiana State University. The survey was completed in October 2016 via telephone interviews. Potential survey respondents came from the water user database managed by the ANRC and all commercial crop growers identified by Dun & Bradstreet records for the state of Arkansas. The final sample size was 199 producers that completed the survey in its entirety.

The dependent variables shown in Table 1 have two types: binary, for use, and the number of acres. There were 174 observations for the binary variables, while the number of acres variables had an observation when there is participation. Only 13% of respondents utilized border irrigation, while 25% used warped surface leveling, and 35% of respondents used deep tillage on their farm. Border irrigation had the lowest use, 92.54 irrigated acres, when evaluating the number of irrigated acres in each practice. On average, farms have 186.90 irrigated acres with warped surface leveling technology. The average number of irrigated acres that used deep tillage is 342.21 irrigated acres.

Peer networks explanatory variables are shown in Table 2. Most variables for the peer networks had a mean between 10% and 50%, with precision leveling the highest at 87%. There were also explanatory variables in our analysis to control for location and socioeconomics. This included the proportion of producers that live along Crowley's Ridge (Ridge), along the Mississippi River (River), in the South Delta (SD), and the North Delta (ND). Other control variables included irrigation practices and other farm management characteristics such as zero grade leveling (ZeroGrade), multiple inlet irrigation (Multi-Inlet), alternating wetting and drying (AltWetDry), participating in conservation reserve program (PartCRP), participating in environmental quality incentives program (PartEQIP), and regional conservation partnership (PartRegCon). Additional variables are the number of acres with irrigated cotton (IrrCottonAcres), the number of acres with irrigated soybeans (IrrSoyAcres), and the number of acres with irrigated rice (IrrRiceAcres). Many producers have attended school and completed their bachelor's degrees (Bach), and a few have gone on to obtain a higher degree (AdvEdu). More than half of the producers reported having some form of agriculture education (AgEdu). Some producers did not report an income (IncNA).

In a sample selection model, the dependent variable in the participation equation, y_1, is an incompletely observed value of a latent dependent variable y_1^*, where the observation rule is:

$$y_1 = \begin{cases} (1 \text{ if}) \\ (0 \text{ if } y_1^* \leq 0) \end{cases}$$

and a resultant outcome equation that:

$$y_2 = \begin{cases} (y_2^* \text{ if } y_1^* > 0) \\ (- \text{ if } y_1^* \leq 0). \end{cases}$$

This model specifies that y_2 is observed when $y_1^* > 0$, whereas y_2 has no meaningful value when $y_1^* \leq 0$. The latent variables y_1^* and y_2^* indicate that the mechanism motivating participation (y_1^*) and the number of acres for a particular irrigation technique (y_2^*) are not observed for all sample observations. The standard approach specifies a linear model with additive errors for the latent variables, so $y_1^* = x_1'\beta_1 + \varepsilon_1$, and $y_2^* = x_2'\beta_2 + \varepsilon_2$, and with the need for non-standard estimation methods of β_2 if ε_1 and ε_2 correlated (Heckman, 1979).

The marginal effects for the participation equation show the change in the probability of participation in response to a unit increased in a given explanatory variable. Marginal effects for the outcome equation are the expected change in y_2 for a change in an explanatory variable, conditional on participation in the use of the irrigation practice. If the independent variable appeared in both the participation and outcome equations, there is an expected change in from direct effect from the explanatory variable in the outcome equation and an indirect effect from the explanatory variable in the participation equation, if there is a correlation in the error terms for the two equations. The maximum likelihood estimation for bivariate sample selection model uses Stata® version 13.1.

Results and Discussion

Having family or friends (i.e., a peer network) that use surge irrigation, users increased the likelihood of border irrigation use by 2.5% and by an additional 19.9% if the producer participated in a federal cost-share program for tailwater recovery system or on-farm reservoir (Table 3). A producer with a zero-grade leveling peer network increased the use of border irrigation by 8.2%. If a producer had a peer network of reservoir users, then they are more likely to use warped surface leveling by 10.2%. Having a flow meter peer network also increased the use of warped surface leveling by 10.9%. Having a multiple inlet irrigation peer network reduced the use of warped surface leveling by 40.4%, but only slightly if the producer is in the Grand Prairie (-0.1%), North Delta (-5%), or along Crowley's Ridge (-2%). This may be due to multiple inlet irrigation being a relatively established practice to increase irrigation efficiency when there is no laser leveling. Also, belonging to a peer network of computerized hole selection or scientific scheduling decreased the use of older practices like border irrigation (-14%) or deep tillage (-20%), respectively. Producers that have either some agriculture education or an advanced college degree are less likely to use deep tillage on their farm. Living in the south delta increased the likelihood that a producer will use warped surface leveling, and living along the Mississippi river reduced the likelihood of using border irrigation. Utilizing atmometers or growing irrigated soybeans has a positive effect on the use of warped surface leveling and deep tillage. However, producers that used soil sensors are less likely to use warped surface leveling.

More peer variables were significant in explaining the number of acres using border irrigation (Table 4). Having a peer network of flowmeter users decreased the number of acres that use border irrigation by about 300 acres, and even more if the producer lived in the Grand Prairie. There is also a negative relationship between producers with a computerized hole selection peer network and the number of acres that utilized border irrigation. Since border irrigation is an older practice, having peers that used newer technologies might reduce the acreage of border irrigation. However, having a network of peers that used surge irrigation slightly increased the number of irrigated acres that use border irrigation by 133 ac; this is especially true if the producer participated in a federal cost-share program for tailwater recovery system or on-farm reservoir or participated in other conservation programs. Producers that have a peer network of reservoir users used fewer irrigated acres with warped surface leveling unless the producer lives in the North Delta or Grand Prairie, and then they will have more irrigated acres that used warped surface leveling. Having a peer network that used zero grade leveling also had a negative effect on the number of warped surface leveling acres. However, there was a positive effect on the number of irrigated acres if the producer had peers that used zero grade leveling and the producer participated in a regional conservation partnership program. Producers with an end blocking peer network also had more irrigated acres that used warped surface leveling.

Producers with peers that used end blocking irrigation or multiple inlet irrigation were more likely to have more irrigated acres that utilized deep tillage. Having a peer network of users of the tailwater recovery system increased the number of irrigated acres with deep tillage unless the producer lived along Crowley's Ridge or in the north delta. Flowmeters and zero grade leveling peer networks decreased the number of irrigated acres in deep tillage by 345 and 461 acres, respectively. Producers that lived in the south delta and have peers that used computerized hole selection have more irrigated acres that utilized deep tillage. However, a producer that lived in the other regions with peers that used computerized hole selection had fewer acres that utilize deep tillage. Having a surge peer network decreased the number of irrigated acres that used deep tillage unless the producer lived in the Grand Prairie. A peer network of precision leveling users had a negative relationship with the number of deep tillage acres unless the producer lived in the north delta. Peer networks of scheduling users lowered the deep tillage acres by 746 acres unless the producers lived along Crowley's Ridge. Producers that lived in the south delta with peers that used alternative wetting and drying have more irrigated acres that used deep tillage, but producers in other regions with alternative wetting and drying had fewer acres that used deep tillage.

More education lowered the number of irrigated acres that utilize border irrigation and warped surface leveling (Table 5). Producers with a degree higher than a bachelor's had 1310 fewer acres of border irrigation and 1416 fewer acres using warped surface leveling. Having a bachelor's degree lowered the acres in border irrigation, but an agriculture education had a positive relationship with the border irrigation acres and a negative relationship with the warped surface leveling acres. Producers that live along Crowley's Ridge, by the Mississippi River, or in the north delta are likely to have more irrigated acres with warped surface leveling. Producers that lived along the Mississippi River had more acres that utilized deep tillage. Producers that participate in a conservation reserve program had less irrigated acres using deep tillage. However, producers that participated in the environmental quality incentives program or the regional conservation partnership program had more acres using deep tillage. Producers that used precision leveling had more land utilizing warped surface leveling. Producers who said that they do not use precision leveling because the cost is too high had fewer irrigated acres that utilize deep tillage and warped surface leveling.

The use of warped surface leveling slightly increased the irrigated acres that used deep tillage and border irrigation. The use of end blocking irrigation decreased slightly the acres with border irrigation. Each additional acre of irrigated cotton made a producer likely to have 0.54 more acres of deep tillage. Each additional acre of irrigated soybeans made a producer likely to have 0.16 more acres of border irrigation and 0.54 fewer acres of warped surface leveling. Each additional acre of rice made a producer likely to have 0.22 and 1.04 more acres that used deep tillage and warped surface leveling, respectively. The longer a producer used precision leveling, the more acres that utilized warped surface leveling. The use of multiple inlet irrigation slightly increased the acres using deep tillage, border irrigation, or warped surface leveling.

The interaction between where producers lived and a peer network variable significantly influenced the number of acres in a particular irrigation practice. Over half of the significant interaction variables in Table 4 were related to the location where a producer lived. The region where a producer lived has a large effect on warped surface leveling and deep tillage but not for border irrigation. Producers having a network of reservoir users or zero-grade leveling users decreased heavily the number of acres that used warped surface leveling. Having peer networks that used particular irrigation practices are among the most influential explanatory variables for understanding Arkansas producers' use of irrigation practices and the number of acres in those practices. Because the analysis does not allow us to determine the direction of the relationship between having a peer network and using an irrigation practice, the producer may have joined the peer network group after implementing a practice on their farm, or the producer may have implemented the use of a practice because their peers used this particular practice. Collecting data over many years would help us analyze the evolution of peer networks over time: how the directionality of the information exchange in the network occurs, or how the size of a particular network changes.

Practical Applications

Knowledge of peer networks allows policymakers to utilize incentives for efficient irrigation practices more cost-effectively. By determining the socio-ecologic factors that influence producers' decision to use a particular practice, policymakers can target incentives in a way to save the industry time and money. For a simple example, our findings suggest that promoting the use of warped surface leveling in an area where the majority of the producers currently use zero grade leveling would not be effective. Having a peer that used zero grade leveling reduced the expected number of acres using warped surface leveling by 2106 acres. However, producers that live along Crowley's Ridge are likely to have 4879 more acres that use warped surface leveling. Companies selling warped surface leveling equipment should then focus their efforts there. Knowledge about how peer networks influence irrigation decisions could prove beneficial for Cooperative Extension Service, government cost-share programs, and businesses that sell irrigation equipment. In addition, this research could increase the spread of efficient irrigation practices and ultimately conserve water in critical areas of the aquifer.

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Table 1. Dependent variables on use or number of irrigated acres for an irrigation practice.

Variable	Definition	Mean	SD
Border	1 if use border irrigation	0.13	-
WarpedSurface	1 if use warped surface/ optisurface	0.25	-
DeepTillage	1 if use deep tillage	0.35	-
Border_Acres	Number of irrigated acres using border irrigation	92.54	372.36
WarpedSurface_Acres	Number of irrigated acres using warped surface/ optisurface	186.90	769.78
DeepTillage_Acres	Number of irrigated acres using deep tillage	342.21	783.06

Number of Observations: 174; SD = Standard Deviation.

Table 2. Explanatory variables on use or number of irrigated acres for an irrigation practice.

Variable	Definition	Mean	SD
Peer Network			
PeerTWR	1 if peers used tailwater recovery system	0.66	--
PeerRes	1 if peers used reservoir storage	0.60	--
PeerCHS	1 if peers used Computerized hole selection	0.52	--
PeerSurge	1 if peers used surge irrigation	0.34	--
PeerFlowMeter	1 if peers used flowmeters on the wells	0.62	--
PeerPLevel	1 if peers used precision leveling	0.87	--
PeerZeroGrade	1 if peers used zero grade leveling	0.71	--
PeerEndBlock	1 if peers used alternate end blocking, cutback irrigation, or furrow diking in irrigation	0.50	--
PeerScheduling	1 if peers used irrigation scheduling such as: soil moisture sensors, ET, and Atmometer	0.49	--
PeerMulti-Inlet	1 if peers used multiple-inlet rice irrigation	0.65	--
PeerAltWetDry	1 if peers used wetting and drying for rice irrigation	0.33	--
PeerTWR*Ridge	1 if peers used tailwater recovery system and located on Crowley's Ridge	0.21	--
PeerTWR*ND	1 if peers used tailwater recovery system and located in the North Delta	0.12	--
PeerRes*GP	1 if peers used reservoir storage and located in the Grand Prairie	0.17	--
PeerRes*SD	1 if peers used reservoir storage and located in the South Delta	0.05	--
PeerRes*RegCon	1 if peers used end blocking and participated in regional conservation partnership program	0.10	--
PeerRes*Fin	1 if peers used reservoir storage and primary reason for adoption was financial assistance	0.05	--
PeerCHS*SD	1 if peers used computerized hole selection and located in the South Delta	0.03	--
PeerCHS*CRP	1 if peers used computerized hole selection and participate in conservation reserve program	0.25	--
PeerCHS*EQIP	1 if peers used computerized hole selection and participated in environmental quality incentives program	0.31	--
PeerCHS*PartOther	1 if peers used computerized hole selection and participate in other conservation program	0.15	--
PeerSurge*GP	1 if peers used surge irrigation and located in the Grand Prairie	0.05	--

Continued.

Table 2. Continued.

Variable	Definition	Mean	SD
PeerSurge*Fed	1 if peers used surge irrigation and payment was through federal program	0.08	--
PeerSurge*PartOther	1 if peers used surge irrigation and participate in other conservation program	0.09	--
PeerFlowMeter*GP	1 if peers used flowmeter and located in the Grand Prairie	0.16	--
PeerPLevel*ND	1 if peers used precision leveling and located in the North Delta	0.12	--
PeerZeroGrade*Ridge	1 if peers used zero grade leveling and located on Crowley's Ridge	0.22	--
PeerZeroGrade*GP	1 if peers used zero grade leveling and located in the Grand Prairie	0.15	--
PeerZeroGrade*ComputerizedHole	1 if peers used zero grade leveling and used computerized hole system	0.27	--
PeerZeroGrade*RegCon	1 if peers used zero grade leveling and participated in regional conservation partnership program	0.11	--
PeerZeroGrade*Fed	1 if peers used zero grade leveling and payment was through federal program	0.19	--
PeerScheduling*CRP	1 if peers used irrigation scheduling and participated in conservation reserves program	0.26	--
PeerMult-Inlet*Ridge	1 if peers used multiple-inlet rice irrigation and located on Crowley's Ridge	0.18	--
PeerMult-Inlet*River	1 if peers used multiple-inlet rice irrigation and located along the Mississippi River	0.12	--
PeerMult-Inlet*GP	1 if peers used multiple-inlet rice irrigation and located in the Grand Prairie	0.16	--
PeerMult-Inlet*ND	1 if peers used multiple-inlet rice irrigation and located in the North Delta	0.10	--
PeerAltWetDry*SD	1 if peers used wetting and drying for rice irrigation and located in the South Delta	0.03	--
Farm, Irrigation, Socioeconomics			
IrrSoy	1 if grows irrigated soy	0.80	--
SoilSensor	1 if use soil moisture to schedule irrigation on farm	0.10	--
ETAtmometer	1 if use ET or atmometer to schedule irrigation times	0.03	-- --
Ridge	1 if county is in Crowley's Ridge	0.31	--
River	1 if county is along Mississippi River	0.23	--
ND	1 if county is in the North Delta and not others	0.13	--
SD	1 if county is in the South Delta and not others	0.07	--
PartCRP	1 if participated in conservation reserve program	0.43	

Continued.

Table 2. Continued.

PartEQIP	1 if participated in environmental quality incentives program	0.45	--
PartRegCon	1 if participated in regional conservation partnership program	0.14	--
PrecisionLevelEasy	1 if used precision leveling to make irrigation easier	0.19	--
NoPrecisionLevelCost	1 if precision leveling is not used because the cost is too high	0.06	--
IrrCottonAcres	Number of irrigated cotton acres (in hundreds)	112.88	458.04
IrrSoyAcres	Number of irrigated soybean acres (in hundreds)	1201.36	1488.40
IrrRiceAcres	Number of irrigated rice acres (in hundreds)	654.79	979.26
YieldCorn	Expected yield of corn (in tens of bushels per acre)	85.85	95.82
PrecisionLevelAge	Year started using precision leveling	1065.18	998.85
ZeroGrade	Number of irrigated acres using zero grade system	49.07	156.62
Multi-Inlet	Number of irrigated acres that are contour levee fields using multiple inlet irrigation	157.02	422.22
AltWetDry	Number of irrigated rice acres managed under alternative wetting and drying	54.10	343.57
AgEdu	1 if formal education related to agriculture	0.56	--
Bach	1 if completed Bachelor's degree	0.42	--
AdvEdu	1 if completed education beyond a Bachelor's degree	0.09	--
IncNA	1 if household income not available	0.23	--

SD = Standard Deviation.

Table 3. Marginal effects of variables to explain the percent use of an irrigation practice.

Variable	Border	Warped Surface	Deep Tillage
Peer Network			
PeerRes	-	0.102 (1.72) c	-
PeerCHS	-0.137 (-2.70) a	-	0.183 (1.17)
PeerSurge	0.025 (2.12)	-	-
PeerFlowMeter	-	0.109 (1.80) c	-
PeerScheduling	-	-	-0.195 (-1.55)
PeerZeroGrade	0.082 (1.85) c	-	
PeerMulti-Inlet	-	-0.404 (-2.00) b	-
PeerAltWetDry	-	-0.154 (-2.53) a	-
PeerCHS*SD	-	-	-0.910 (-1.95) b
PeerCHS*CRP	-	-	-0.287 (-1.94) b
PeerCHS*PartOther	0.081 (1.71) c	-	-
PeerSurge*Fed	0.199 (2.56) a	-	-
PeerScheduling*SD	-	-	0.807 (1.97) b
PeerScheduling*CRP	-	-	0.331 (2.12) b
PeerMult-Inlet*Ridge	-	0.377 (1.72) c	-
PeerMult-Inlet*GP	-	0.402 (2.03) b	-
PeerMult-Inlet*ND	-	0.346 (1.57) c	-
Farm, Irrigation, Socioeconomics			
IrrSoy	-0.084 (-2.08) b	0.375 (3.49) a	0.325 (2.61) a
SoilSensor	-	-0.247 (-2.30) b	-
ETAtmometer	-	0.514 (3.05) a	0.468 (2.01) b
River	-0.134 (-2.45) a	-	-
SD	-	0.467 (2.38) a	-
ZeroGrade	0.000 (2.12) b	-	-
AgEdu	-	-	-0.168 (-2.21) b
AdvEdu	-	-	-0.314 (-1.92) b

Note: a, b, c represents significance at 1%, 5%, and 10% levels, respectively. Z statistics from the probit model estimates in parentheses.

Table 4. Marginal effects of variables to explain the number of acres using an irrigation practice.

Variables	Border	Warped Surface	Deep Tillage
Peer Network			
PeerTWR	-	-	651.8 (3.03) a
PeerRes	-	-1350.7 (-3.50) a	-
PeerCHS	-299.3 (-2.13) b	-	-59.13 (-0.31)
PeerSurge	133.0 (0.90)	-	-752.3 (-3.98) a
PeerFlowMeter	-851.6 (-3.71) a	-	-344.6 (-2.07) b
PeerPLevel	-	-	-466.1 (-1.99) b
PeerZeroGrade	163.9 (1.44)	-2106.1 (-2.81) a	-460.8 (-2.81) a
PeerEndBlock	-	1169.7 (3.10) a	238.9 (1.79) c
PeerScheduling	-	-	-746.6 (-3.68) a
PeerMulti-Inlet	-	-	757.4 (3.30) a
PeerAltWetDry	-	-	-284.6 (-1.93) b
PeerTWR*Ridge	-	-	-736.5 (-2.30) b
PeerTWR*ND	-	-	-1775.4 (-3.48) a
PeerRes*GP	-	3701.6 (3.53) a	-
PeerRes*SD	-	3815.3 (3.87) a	-
PeerRes*RegCon	-	-2091.5 (-1.74) c	-
PeerRes*Fin	-	-1399.4 (-2.51) a	-
PeerCHS*SD	-	-	1665.2 (3.31) a
PeerCHS*EQIP	-370.2 (-2.37) a	-	-
PeerCHS*PartOther	342.3 (2.43) b	-	-
PeerSurge*GP	-	-	1381.2 (4.63) a
PeerSurge*Fed	748.6 (3.27) a	-	-
PeerSurge*PartOther	697.7 (3.14) a	-	-
PeerFlowMeter*GP	-603.5 (-2.61) a	-	-
PeerPLevel*ND	-	-	1355.8 (3.39) a
PeerZeroGrade*Ridge	-	2711.6 (2.99) a	-
PeerZeroGrade*GP	-	1642.8 (1.75) c	-
PeerZeroGrade*ComputerizedHole	-	794.1 (2.00) b	-
PeerZeroGrade*RegCon	-	3144.5 (3.41) a	-
PeerZeroGrade*Fed	-262.7 (-1.67) c	608.5 (1.62) c	-
PeerScheduling*Ridge	-	-	842.9 (2.89) a
PeerMult-Inlet*River	-	-	-704.4 (-1.89) b
PeerAltWetDry*SD	-	-	570.9 (1.61) c

Note: a, b, c represents significance at 1%, 5%, and 10% levels, respectively. Z statistics from the probit model estimates in parentheses.

Table 5. Marginal effects of variables to explain the number of acres using an irrigation practice.

Variables	Border	Warped Surface	Deep Tillage
Farm, Irrigation, Socioeconomics			
PrecisonGrade	-	-	0.358 (6.02) a
WarpedSurface	0.994 (4.15) a	-	0.499 (2.85) a
EndBlock	-1.27 (-6.20) a	-	-
DeepTillage	-	-0.781 (-3.20) a	-
ETAtmometer	-	-	-1331.2 (-3.92) a
Ridge	-	1752.4 (1.80) c	-
River	-	4878.9 (5.35) a	1399.1 (4.75) a
ND	-	2190.9 (3.00) a	-
PartCRP	-	-	-843.7 (-5.24) a
PartEQIP	-	-	494.3 (2.79) a
PartRegCon	-	-	773.3 (4.27) a
PrecisionLevelEasy	-	1087.8 (3.04) a	-
NoPrecisionLevelCost	-	-2200.9 (-3.90) a	-1247.6 (-3.99) a
IrrCottonAcres	-	-	0.537 (3.00) a
IrrSoyAcres	0.164 (2.24) b	-0.542 (-3.23) a	-
IrrRiceAcres	-	1.04 (2.88) a	0.223 (3.50) a
YieldCorn	-5.68 (-7.86) a	-	-
PrecisionLevelAge	-	1.46 (7.50) a	0.266 (3.71) a
ZeroGrade	0.507 (1.91) b	-	-3.01 (-4.71) a
Multi-Inlet	0.581 (2.48) b	1.31 (3.92) a	0.314 (2.08) b
AltWetDry	-	-	0.370 (2.42) a
AgEdu	710.3 (4.15) a	-950.0 (-2.26) b	-
Bach	-440.1 (-2.96) a	-	-
AdvEdu	-1310.3 (-4.91) a	-1416.3 (-2.08) b	-
IncNA	-	-	-378.1 (-2.48) a

Note: a, b, c represents significance at 1%, 5%, and 10% levels, respectively. Z statistics from the probit model estimates in parentheses.

Soybean Sap Flow and Water Demand for Late-Season Growth Stages

M. Ismanov,[1] C.G. Henry,[2] L. Espinoza,[1] and P.B. Francis[3]

Abstract

Soybean plant transpiration can be measured with sap flow and used to determine crop water use. The objective of this research was to determine crop water use by the soybean growth stage, variety and planting date as it affects transpiration and accumulated dry matter yield. This information can be used to predict irrigation needs in conjunction with the soil water balance to improve the water management and profitability of soybean production.

Introduction

The water demand of soybean varies with growth stage and weather conditions (Payero and Irmak, 2013). For example, the sap flow rates of soybean are lower in humid conditions than arid conditions (Akihiro and Wang, 2002). Thus transpiration rates of crops must be determined for different climatic regions. Sap flow is regulated by soil moisture, solar radiation, air temperatures, and vapor pressure deficits (Zhao et al., 2017; Ismanov et al., 2018).

Ismanov et al., 2018 found that the leaf energy balance could be evaluated with solar radiation efficiency (SRE), defined as the ratio between hourly solar energy received by the plant and the amount of sap flow. The SRE was found to be relatively higher in the morning hours, lower in afternoon hours, and slightly increased at the end of the day. Understanding sap flow characteristics in different soil-water resistance, growth stages, and weather conditions, including solar radiation, ambient air temperature, and relative humidity, will help improve irrigation scheduling, yields, yield uniformity, and soybean water management efficiency.

According to Kranz and Specht, 2012, plant water demands for soybean are highest during the reproductive stages; about 65% of water use occurs from R1 (beginning flower) through maturity. Soybean is most sensitive to water stress during the mid- to late-reproductive stages: pod development (R3 to R4) and seed fill (R5 to R6). A lack of understanding exists concerning water use in soybean in the humid region. Identifying water use by growth stage can be used to predict irrigation timing and water needs.

Procedures

Research to investigate soybean sap flow of different soybean maturity groups and planting dates was conducted at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station, at Marianna, Ark., during 2017–2019.

Sap flow was measured using a Dynamax low 32 1-K (http://dynamax.com) system with SGA5-WS and SGB9-WS sap flow sensors from R2 (late flowering) until R8 (maturity) growth stages.

WatchDog 2900 Evapotranspiration (ET) weather stations (www.specmeters.com) with our modifications and Model E electronic pulse output ET gages (www.etgage.com) with EL-USB-5 data logger (www.lascarelectronics.com) recorded weather parameters and potential evapotranspiration. Air temperature and relative humidity (RH) sensors were installed 2–3 in. above and 10–15 in. under the canopy and adjusted with plant height changes. Soil moisture profiles were measured using Watermark® sensors. Gravimetric soil water contents were measured several times to calibrate the soil moisture sensors throughout the season.

Soybean leaf/canopy temperature was continuously measured in ten-minute intervals using an infrared temperature (IR) transmitter OS137A-1-MA (www.omega.com). Also, the plant leaf, pod, stem, and the soil surface temperatures were measured by an infrared thermometer (www.specmeters.com). Leaf area and pod mass were measured weekly, and plant moisture content measured every growth stage.

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Results and Discussion

The measurements were used to assess plant water use, and careful notes were taken during the study. Plant growth is highest during the reproductive stage and then is reduced towards the end of the season. Peak transpiration was measured around 0.2–0.25 in./day. Accordingly, the higher plant sap flow rates correspond to maximum rates of biomass calculated as a volume of the plants per row foot:

$$W_b = kHBL,$$

where k = coefficient depending on the vertical profile of the soybean plant that varies for different varieties and usually changes from 0.65 to 0.85; H = height of the plant; B = width of the plant; L = length of the row. The examples of the biomass for two soybean varieties planted on two different dates and sap flow rates are given in Fig. 1. The relationship between biomass and sap flow can be represented by the following two equations: Y_1=-0.0003X + 0.0516 and Y_2=-0.0006X + 0.0709, inch/ft^3, respectively for the soybeans planted 1 May and 28 May 2019. Here, X is the days after the emergence of the plants. The sap flow per cubic foot biomass is higher in the younger and smaller plants than in the older and larger plants. This may be due to better sun exposure and air movement. Lower leaves of the bigger plants, especially when LAI ≥ 1, were not exposed to full solar radiation and wind speed that decreases the transpiration rates from their surface. Also, the biomass of the soybean rows raises the air temperature and humidity differences beneath and above the canopy. The higher air humidity under the canopy, due to intensive transpiration rates of the plant, significantly decreases the water transpired from the lower leaves. The sap flow model of the soybean variety Pioneer P31A06L planted on the 1 May 2019 (Fig. 2) shows that the soybean plant in vegetative stages uses a little more than 2% of the total water required during the entire soybean growing season. The average total water needs from R1 to R7, 10.4%, or 1.6 in. of water, is required during the R1 and R2 growing stages, and 14.3% or 2.0 in. of water is used during the R3 stage. In our experiments, sap flow measurements with other varieties and planting timings show that the water use in R2 and R3 growth stages may require as much as 2.5–3.5 in., especially in mid- and late-planted soybean. During the R4 to R6 growth stages, 9.2 in., or 65.7% of total soybean water demand, is required. Water use was found to be 1.3 inches in the final R7 and R8 stages. It's noticeable that lower rates of ET could slow the biological activity of the plant development and increase the time a plant resides in a growth stage. This was observed as the length of time soybean plants were in the R4 growth stage relative to the R3 and R5 stages. It should be noted that the data is highly variable from year to year.

The soybean plant sap flow amounts planted on different dates between the years of 2017–2019 (Table 1) show that water use in different stages depends on soybean variety, planting time, and duration of the stage. The R6 growth stage transpired the most compared to the time it took to mature in the respective growth stage.

Water use begins to decline during the R6 growth stage. It was observed that at the end of the stage (R6.9), the daily water use is much less compared to the beginning of R6. Sap flow in the R7 and R8 stages, when plants retain just a few green leaves, resulted in a 3 ºF to 4 ºF lower surface temperature of the green pods when compared with the ambient air temperature. Also, the expected diurnal transpiration rate was observed during this study.

A comparison of soybean yield and sap flow shows the balance of these two factors: higher yields are produced by the soybean with higher accumulated sap flow in the year. The similar proportions established between crop yield with accumulated heat units and sap flow help to accurately predict the soybean yield depending on the weather and climate conditions.

Practical Applications

The modeling of the soybean plant water demand in all vegetative and reproductive stages can be used to improve irrigation management by providing crop water use that can be used to predict the amount of water needed to finish a crop. The initiation of irrigation should begin if the precipitation is inadequate to meet water demands at early reproductive stages and soil water is inadequate to meet demand. This is more likely to occur in later-planted soybeans. The data in Table 1 can then be adapted for recommendations for sub-humid soybeans by planting date to predict irrigation needs. When used with irrigation scheduling tools, such as checkbook schedulers or soil moisture sensors this data can be used to determine when adequate soil moisture exists to terminate irrigation.

Increasing our knowledge of soybean moisture dynamics allows for more precise and efficient irrigation scheduling methods and more efficient water use. Adoption of multiple crop monitoring strategies, such as soil moisture sensors, on-site weather monitoring, canopy temperatures, and light reflectance, can be a more accurate way of determining when to irrigate provided if the relationships between these planting dates, transpiration, dry matter accumulation, and crop yields are understood. Reliable and affordable technology for monitoring these parameters is being developed. This information can be used to develop methodologies for more productive crop water management decisions.

Acknowledgments

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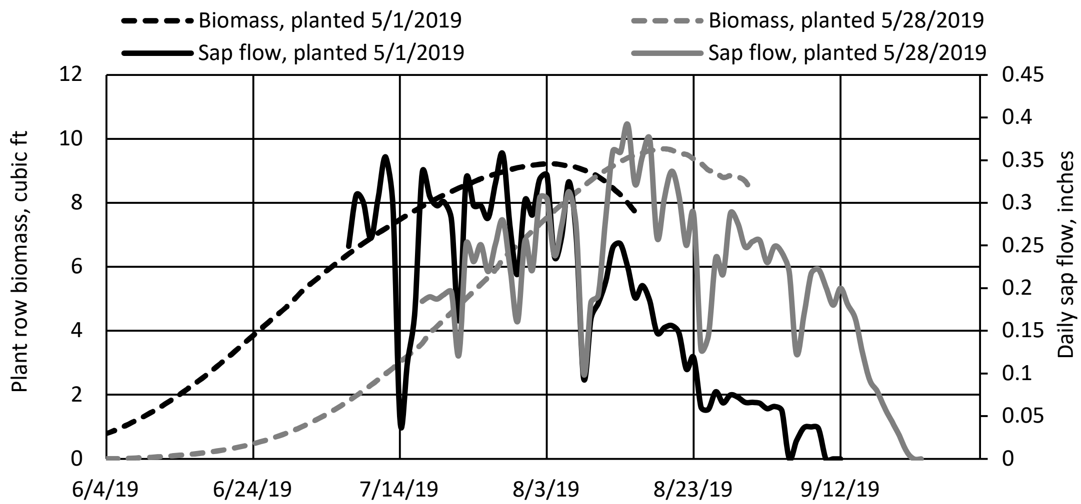

Fig. 1. The relationship between daily sap flow and biomass calculated in soybean planted at two different timings.

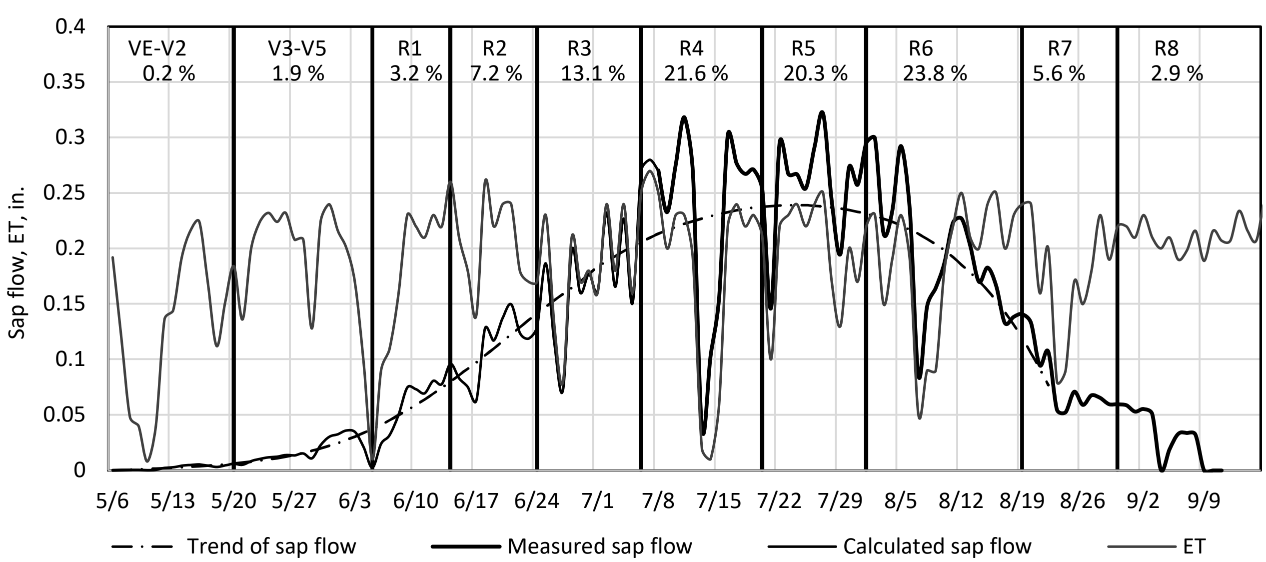

Fig. 2. Soybean water use as the measured and calculated plant sap flow and evapotranspiration (ET) during the whole vegetative and reproductive growth stages.

Table 1. Daily and accumulated plant sap flow amounts in different growth stages of soybeans planted with different timings in 2017–2019.

Year	2019						2018				2017		2019–2017	
Variety	Pioneer P31A06L		Pioneer P40A03L		Pioneer P40A03L		Pioneer P35T75X		Pioneer P40A47X		Dyna-Gro 39RY43		In three years	
Planted	5/1		5/28		6/30		5/4		5/28		4/16		4/16…6/30	
Harvested	9/13		9/30		10/19		8/28		9/16		9/21		9/13…10/19	
Days	135		125		111		116		111		158		111…158	
Stages	**Avg.**	**Sum**	**Avg.**	**Sum**	**Avg.**	**Sum**	**Avg.**	**Sum**	**Avg.**	**Sum**	**Avg.**	**Sum**	**Avg.**	**Sum**
R4	0.22	3.3	0.31	3.59			0.28	2.2	0.27	2.1	0.25	2.3	0.27	2.62
R5	0.26	3.1	0.29	3.06			0.26	1.8	0.27	1.6	0.29	2.9	0.27	2.42
R6	0.20	1.8	0.29	2.1	0.24	1.7	0.29	2.3	0.14	1.1	0.18	1.8	0.22	1.79
R6.5	0.21	1.0	0.22	1.62	0.20	0.8	0.23	1.9	0.12	0.9	0.15	1.6	0.19	1.26
R6.9	0.12	0.8	0.18	0.58	0.11	0.3	0.26	1.0	0.12	0.5	0.07	0.5	0.15	0.58
R7	0.08	0.9	0.07	0.37	0.03	0.2	0.08	1.0	0.04	0.5	0.03	0.5	0.06	0.57
R8	0.02	0.4	0.00	0.01	0.01	0.1	0.06	0.3	0	0.0	0.02	0.3	0.02	0.17
R4-R6	0.20	10.0	0.26	11.0	0.22*	6.9*	0.26	9.2	0.18	6.3	0.19	9.2	0.22	8.51
R7-R-8	0.05	1.3	0.04	0.4	0.02	0.2	0.07	1.3	0.02	0.5	0.03	0.8	0.04	0.74
Yield bu./ac	45.7		62.6		35.5		80.5		62.3		44.8		55.2	

*data was extrapolated.

Irrigation Termination Timing and Interactions With Crop Protectants in Northeast Arkansas Soybeans

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Abstract

Irrigation termination timing for indeterminate soybean [*Glycine max* (L.) Merr.] on clayey soils is typically gauged in relation to crop maturity with the recommendation that final irrigation should be applied at the R6 (full seed) growth stage. Our research question in 2019 was to examine whether extended irrigation would be beneficial if the soybean production system included protectant pesticides. An on-farm irrigation trial was carried out in Mississippi County, Arkansas, to examine the effects of timing of the last furrow irrigation on soybean yield with and without protective fungicide sprays. Irrigation treatments were rainfed, early termination (R5.5), recommended timing (R6), and extended irrigation (R6.5). The multifactor experiment also included either a preventative fungicide application at R3 or no fungicide. A moderately disease-resistant cultivar, Credenz 4918LL, was planted 4 June in Sharkey-Crevasse complex. Weekly scouting included plant growth stage assessments and insect pest and disease monitoring. Soil moisture was monitored using Watermark Sensors. Yields were measured using the cooperating farmer's yield monitor. No differences among treatments in foliar disease symptoms for frogeye leaf spot (FLS) were observed through the season, and no insect pest response to irrigation was detected. Irrigation treatments significantly affected yield ($P = 0.007$). Fungicide sub-plot effects were not significant; however, there was a significant irrigation× fungicide interaction ($P = 0.001$). Lowest yields were observed in rainfed treatments. The highest overall yield was associated with final irrigation at R6 and no fungicide. If irrigation was extended until late R6.5, there was a positive yield response only if there was a protective fungicide application; however, the mean yield was no different than the recommended termination timing with no costly fungicide. These results reinforce the current recommendations to select disease-resistant cultivars; and if needed on clay soils, time the final furrow irrigation at R6.

Introduction

Irrigation termination timing decisions for soybean in the humid mid-south are often challenging, particularly for producers managing crops on heavy clay soils. Late season irrigation followed by early fall rains can delay harvest, risking yield and quality loss. Late-season irrigation followed by early fall rains can delay harvest and result in excessive field rutting during harvest operations. Rutted field conditions require extensive tillage and increase the potential for delayed planting of the subsequent crop. Pumping costs also tend to be higher in late season because of increased depth to groundwater following a long irrigation season. Extended irrigation may exacerbate insect pest risks and favor disease development. Unneeded irrigation applications are an inefficient use of precious water resources.

Irrigation termination timing recommendations for Arkansas soybean are based on predominant soil texture as well as plant growth stage (Henry et al., 2014) and historically have suggested R6 as an irrigation endpoint (Tacker and Vories, 1998). Recommendations from Mississippi suggest that irrigation should be applied at R6 to supply needs to R6.5, and termination at R6.5 (Krutz and Roach, 2016).

Frogeye leaf spot (FLS), caused by the fungal plant pathogen *Cercospora sojina* Hara, has been recognized as an economically important disease by northeast Arkansas soybean producers, and automatic application of fungicides has become a common practice for many high input producers. Warm (77–86 °F) and wet conditions (rain, heavy dew, irrigation > 90% relative humidity) favor disease development (Grau et al., 2004). The timing of the appearance of disease symptoms is an important factor in disease severity and economic impact. If symptoms do not occur until at or after growth stage R5, there is very little impact on the plant, but should severe symptoms appear before or at flowering, then disease can negatively impact yield, particularly in sus-

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ceptible varieties (Lin and Kelly, 2018). The use of costly fungicides may be unnecessary if disease-resistant cultivars are used (Faske, 2019).

This 2019 field trial was conducted to validate current irrigation termination recommendations, including possible interactions with fungicidal protectants effective against soybean foliar diseases including FLS.

Procedures

The experiment was conducted in a 60–acre commercial field in Dell in Mississippi County, Arkansas (35°53'02.0"N 89°59'52.1"W). The 3 × 4 factorial experiment was arranged in a split-plot design with 4 replications. Main-plot treatments were final irrigation applications scheduled at 1) R5.5, 2) R6, 3) R6.5, and 4) rainfed check. Pest control sub-plot treatments were 1) Automatic fungicide at R3 and 2) unsprayed check. The field was planted 4 June 2019 with Credenz 4918LL, (indeterminant, MG 4.9 with moderate resistance to frogeye leaf spot). Furrow irrigation water was delivered using poly-pipe in every furrow. Irrigation dates and other production timing are listed in Table 1. The automatic fungicide application (Preaxor® 4.17 SC 7 oz/ac (pyraclostrobin+fluxapyroxad; FRAC Code 11+7)) was made 6 August (63 days after planting (DAP)). All standard field operations were similar across the field, with only irrigation and fungicide applications altered among treatments. Soil moisture measurements were monitored using Watermark sensors (Irrometer; Riverside, Calif.) installed at two depths (6 and 12-in.) and positioned at the top of the bed at two sites near the center of each irrigation plot. Weekly plant and pest monitoring included assessments of growth stage and sweep net and drop cloth sampling for insect pests. Disease symptoms were monitored in the weekly examination of upper canopy trifoliates starting at R5. Scouts inspected 25 plants per plot, recorded counts of leaf spots (lesions) per trifoliate, and ranked disease severity as either high (>30 spots), medium (10–30), or low (<10). Harvest was completed 18 November, and yield monitor measured yield data were used to evaluate treatment effects. Data were analyzed using Proc Mixed and Proc GLIMMIX (SAS 9.4) with means separated using the LSMEANS procedure.

Results and Discussion

Rainfall amounts during the 2019 season exceeded 30-year averages for the county (Table 2); however, there was a dry period in August through September that enabled comparisons of irrigation timing regimes. Differences in soil moisture availability among treatments were apparent from Watermark sensors readings (Fig. 1), particularly following irrigations made at 91 and 105 DAP. Sensor readings reached the recommended triggers for those final two irrigation applications (75 centibars at growth stages R3-R6) (Krutz and Roach, 2016). Variation in visual disease symptomology for FLS was low and similar among fungicide treated and check plots, which were interpreted as low levels of disease (data not shown). Yield data indicated no significant response to fungicide ($P = 0.24$). Irrigation effects were significant ($P = 0.007$); however, there was a significant irrigation × fungicide interaction ($P = 0.001$) (Table 3 and Fig 2). The highest yield was associated with unsprayed treatment with the final irrigation at R6. If irrigation was extended until late R6.5, then the fungicide appeared to protect yield although it was not statistically significant.

An integrated pest management (IPM) approach to plant disease management emphasizes the use of disease resistance cultivars, which can eliminate the need for costly, preventative chemical control. These data provide support for the use of resistant cultivars, irrigation termination at the R6 growth stage on clay soils, and the use of soil moisture sensors for timing irrigation.

Practical Applications

The use of soil moisture monitoring and appropriate field irrigation thresholds can help producers avoid unnecessary irrigation and improve water management efficiency while maintaining yields. Adoption of improved irrigation scheduling and recommended IPM tactics are expected to allow producers to increase profitability and contribute to a sustainable soybean production system.

Acknowledgments

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Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the view of the U.S. Department of Agriculture.

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Table 1. Timing for irrigation termination and fungicide application including plant growth stage, dates, and number of days after planting, 2019 Dell, Arkansas.

		Treatment timing		
Treatment		**Growth stage**	**Date**	**Days after planting**
Irrigation† Termination	Rainfed (check)	-	-	-
	Early termination	R5	9 August	66
	Recommended	R6	3 September	91
	Late termination	R6.5	17 September	105
Fungicide Application	No application (check)	-	-	-
	Automatic Fungicide	R3	6 August	63

†All irrigated treatment plots received irrigation at 52 and 66 days after planting.

Table 2. Monthly precipitation (inches) measured at the study site for the 2019 season compared with the 30-year average for the county, 2019 Dell, Arkansas.

Mean per month	30-year Average	2019 Rainfall	Departure
	----------------------------inches----------------------------		
June	3.89	5.22	1.33
July	3.47	9.82	6.35
August	2.45	3.14	0.69
September	2.72	0.21	-2.51
October	3.99	0.64	-3.35
Total Season	15.76	44.32	28.56

Table 3. Mean yield for each irrigation and fungicide treatment combination, 2019 Dell, Arkansas.

Irrigation	Fungicide†	Yield‡
		bu./ac
Rainfed	Untreated Check	27.3 c†
Rainfed	Automatic Fungicide	29.4 bc
R5.5	Untreated Check	27.9 c
R5.5	Automatic Fungicide	29.5 bc
R6	Untreated Check	39.1 a
R6	Automatic Fungicide	32.6 bc
R6.5	Untreated Check	32.2 bc
R6.5	Automatic Fungicide	33.6 ab

† Cost of fungicide was $26.17 per acre not including the application cost.
‡ Means followed by similar letters are not different.

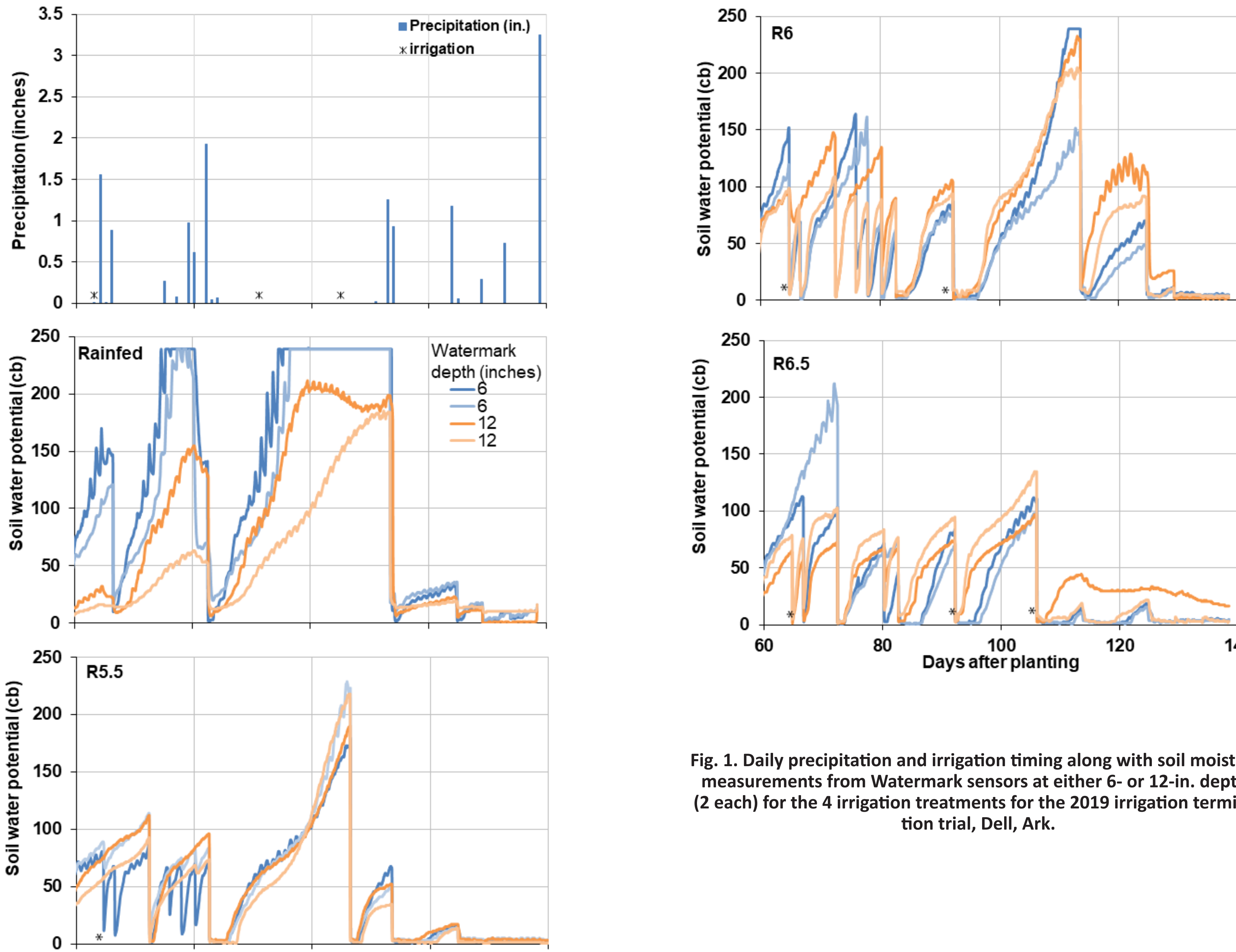

Fig. 1. Daily precipitation and irrigation timing along with soil moisture measurements from Watermark sensors at either 6- or 12-in. depths (2 each) for the 4 irrigation treatments for the 2019 irrigation termination trial, Dell, Ark.

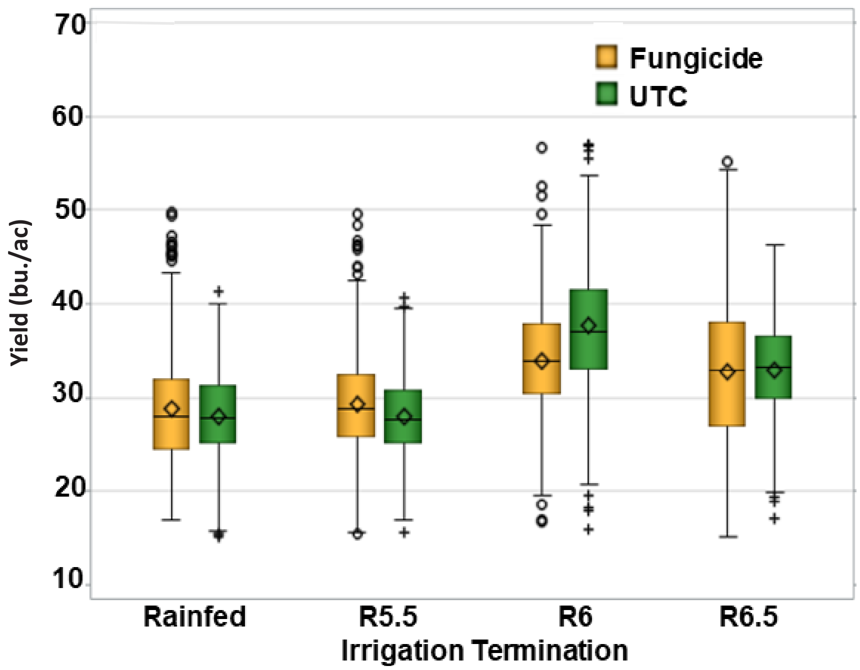

Fig. 2. Soybean yield (bu./ac) from yield monitor measurements in 2019 irrigation termination × fungicide trial in Dell, Arkansas. Boxes represent 50% quartile; diamonds within the box depict means, and the line is the median value; UTC = untreated check.

Soybean Foliar Fertilizer Product Trial

W.J. Ross,[1] J.P. Schafer,[1] and R.D. Elam[1]

Abstract

Many soybean [*Glycine max* (L.) Merr.] producers apply foliar nutrient products during soybean reproductive growth as a routine production practice. These applications are made in addition to the use of commercial fertilizer products applied to the soil. Due to the narrowing of production margins, many have questioned if these foliar nutrient products increase soybean grain yield and are profitable. In 2019, Arkansas collaborated with 12 other soybean-producing states to compare the soybean grain yield response to six commercially available foliar nutrient products. Results from the two locations in Arkansas showed no significant yield increase with any of the products evaluated compared to the untreated check. From these initial results, using these products as a routine production practice would not be recommended.

Introduction

Soybean [*Glycine max* (L.) Merr.] is a nutrient-intensive crop, requiring relatively large amounts of nitrogen (N), phosphorus (P), and potassium (K) compared to corn (*Zea mays*) and rice (*Oryza sativa*) (Slaton et al., 2013). A majority of the required nutrients either come from applied fertilizers or nutrients in the soil. Over the past few years, producers have been inundated with advertisements and pressure from many companies to apply foliar fertilizers to their soybean crop. The marketing of many of these products claims to increase grain yield and plant health. Over the past few years, some producers have been applying foliar nutrient products as a routine practice.

Soybean producers often use these products while applying fungicides and/or insecticides during early soybean reproductive growth. Some producers believe there is a yield increase with applications of N and K at the R3 growth stage. Others believe that micronutrients such as boron (B), manganese (Mn), and iron (Fe) are increasing soybean yield. Due to low-profit margins, the effect of these foliar fertilizers on soybean yield and economic return is important to understand.

Under normal growth, the primary source of macronutrients (N, P, K, and sulfur [S]) is from the soil or biological N fixation. Foliar nutrient products cannot supply sufficient amounts of these nutrients to meet all of the plant's requirements. However, micronutrients such as B, copper (Cu), Fe, Mn, and zinc (Zn) can prove beneficial as a foliar feed, if deficiency symptoms exist.

In 2019, 13 states totaling 20 environments tested foliar nutrient products that were selected with the input of industry professionals. The objectives for this study were to 1) identify yield response in soybean to foliar nutrient applications, 2) conduct economic analyses on the value of these products, and 3) extend these results to soybean producers through Extension networks. This paper will only focus on the two locations that were established in Arkansas, and only report the yield comparisons of the products tested in 2019.

Procedures

Trials were established at the University of Arkansas System Division of Agriculture's Newport Extension Center (NEC), Newport, Ark., and at the Pine Tree Research Station (PTRS), near Colt, Ark. in 2019. The soybean variety Asgrow AG46X6 (Bayer Crop Science; Leverkusen, Germany) was used for each trial, which was a 4.6 maturity group Roundup Ready 2 Xtend® soybean variety seeded at a rate 150,000 seed/ac. Plots consisted of four rows spaced 15 in. by 35-ft long. Trials were planted using a Precision Kincaid Vacuum Plot Planter (Kincaid Equipment Manufacturing; Haven, Kan.) at both the NEC and PTRS on 7 July and June 15, respectively. After planting, a composite soil sample was taken for each plot. The average values of selected soil chemical properties are listed in Table 1. Foliar nutrient products used in this study were selected with the input of industry representatives, and the associated application rates are provided (Table 2). Treatments were applied at the R3 growth stage using a backpack sprayer with a 3-nozzle boom calibrated to deliver a constant carrier volume of 20 gal/ac. Nutrient amounts for each product at the rate for each product are listed in Table 2. Foliar tissue samples were taken imme-

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diately before application, and 14 days after the application for nutrient analysis (data not shown). Management concerning irrigation, fertility, and late-season pest control closely followed recommendations from the University of Arkansas System Division of Agriculture's Cooperative Extension Service for soybean production. In each trial, soybean was irrigated as needed using over-head or flood irrigation at the NEC and PTRS, respectively. At maturity, plots were harvested, and the moisture content and weight of the grain were determined. Grain yield was adjusted to 13% moisture and reported as bu./ac for each trial.

Within each test, treatments were arranged as a randomized complete block design with 6 replications. Data were subjected to analysis of variance (ANOVA), using ARM 2020 (Gylling Data Management, Inc., Brookings, S.D.). When appropriate, mean separations were performed using Fisher's protected least significant difference method with an alpha level of 0.10.

Results and Discussion

Soybean grain yield varied across locations; therefore statistical analysis was conducted by location. At the NEC location, the average soybean grain yield for the foliar nutrient products applied ranged from 53.2–56.7 bu./ac. Soybean grain yields from each treatment were not significantly different from the untreated check (53.7 bu./ac) (Table 3; Fig. 1). The Sure K treatment had the highest numerical grain yield (56.7 bu./ac) of all of the treatments. Of the products tested, the three products that contained K (FertiRain, Sure K, and Maximum NPact K) numerically had the overall highest grain yield.

Results from the PTRS location were similar to those observed at the NEC location. Soybean grain yields of the treatments were not significantly different from the untreated control (62.7 bu./ac). Average grain yields for the foliar nutrient products at the PTRS location ranged from 60.3–65.2 bu./ac. As was observed at the NEC location, the highest soybean grain yields were seen from the three products that contained K (Table 3; Fig. 2).

At both locations, the recommended pre-plant fertilizer was applied according to soil analysis. Therefore, this study was evaluating the effect of selected foliar nutrient products where adequate fertilizer had been applied to maximize soybean grain yield. Results from these trials indicated that additional foliar nutrient products did not significantly increase soybean grain yield, where proper pre-plant fertilizer was applied.

The 2019 results observed in Arkansas were similar to the results seen in most of the other states that conducted this study. Of the 20 sites in 2019, significant differences in yield between treatments were only observed at one site in Wisconsin (data not shown). At this Wisconsin site, Maximum NPact K was the only treatment that yielded significantly higher than the untreated control. This trial will be conducted again in 2020 across the primary soybean growing regions of the U.S.

Practical Applications

The data presented in this paper indicates that under normal soybean production with recommended fertilizer nutrients applied to the soil based on soil test data, the addition of foliar nutrient products do not increase soybean yield. These products could be of benefit in situations where nutrient deficiencies are observed, but should not be used as a routine practice. With the current volatility in the soybean market and the increase in production costs, foliar nutrient products do significantly increase soybean yield and do not have a positive economic return.

Acknowledgments

The authors would like to thank the Arkansas Soybean Promotion Board for their funding of this research. We would also like to thank the personnel at the Newport Extension Center and the Pine Tree Research Station for the help and support of our fieldwork. Support was also provided by the University of Arkansas System Division of Agriculture.

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Table 1. Selected soil chemical property means from the 0–4 in. depth for the nutrient product trials conducted at two University of Arkansas System Division of Agriculture locations in 2019.

Location[a]	Soil Series	pH	P	K	Ca	Mg	SOM
			---------------------------ppm--------------------------				%
NEC	Dexter silt loam	6.3	101	127	621	18.7	1.6
PTRS	Calhoun silt loam	6.7	23	76	1175	208	2.0

[a]NEC = Newport Extension Center, Newport, Ark.; PTRS = Pine Tree Research Station, Colt, Arkansas; SOM = soil organic matter.

Table 2. Amounts of nutrients applied for each product tested at the given rates in 2019.[a]

Treatment	Company	Rate	N	P	K	S	Mn	Fe	Mo	Zn	B	Other
			----	----	----	----	----	lb/ac	----	----	----	----
FertiRain	AgroLiquid	3 gal/ac	3.5	0.9	0.9	0.5	0.02	0.03	--	0.03	--	--
Sure K	AgroLiquid	3 gal/ac	0.6	0.3	1.7	--	--	--	--	--	--	--
HarvestMore Ureamate	Stoller	2.5 lb/ac	0.1	0.25	--	--	0.01	--	0.002	0.01	0.004	Ca, Mg, Co, Cu
Smart B-Mo	Brandt	1 pt/ac	--	--	--	--	--	--	0.006	--	0.07	--
Smart Quarto Plus	Brandt	1 qt/ac	--	--	--	0.04	0.08	--	0.003	0.08	0.06	--
Maximum NPact K	Nutrien	1.5 gal/ac	1.9	--	1.9	--	--	--	--	--	--	--

[a]N = Nitrogen; P = Phosphorus; K = Potassium; S = Sulfur; = Mn = Manganese; Fe = Iron; Mo = Molybdenum; Zn = Zinc; B = Boron

Table 3. Mean soybean grain yield (standard deviation) for selected foliar nutrient products at two University of Arkansas System Division of Agriculture locations in 2019.

Location[a]	UTC	FertiRain	Sure K	HarvestMore UreaMate	Smart B-Mo	Smart Quarto Plus	Maximum NPact K	
	----	----	----	Yield (bu./ac)	----	----	----	
NEC	53.7 (4.7)	54.4 (4.5)	56.7 (6.3)	53.2 (7.1)	53.4 (7.9)	53.6 (8.4)	54.2 (8.2)	NS[b]
PTRS	62.7 (7.0)	63.5 (6.8)	64.7 (5.5)	60.3 (6.3)	62.7 (2.3)	62.6 (6.4)	65.2 (8.2)	NS

[a] NEC = Newport Extension Center, Newport, Ark.; PTRS = Pine Tree Research Station, Colt, Ark.

[b] No statistical difference was seen between the untreated control (UTC) and the foliar nutrient products evaluated at α = 0.10.

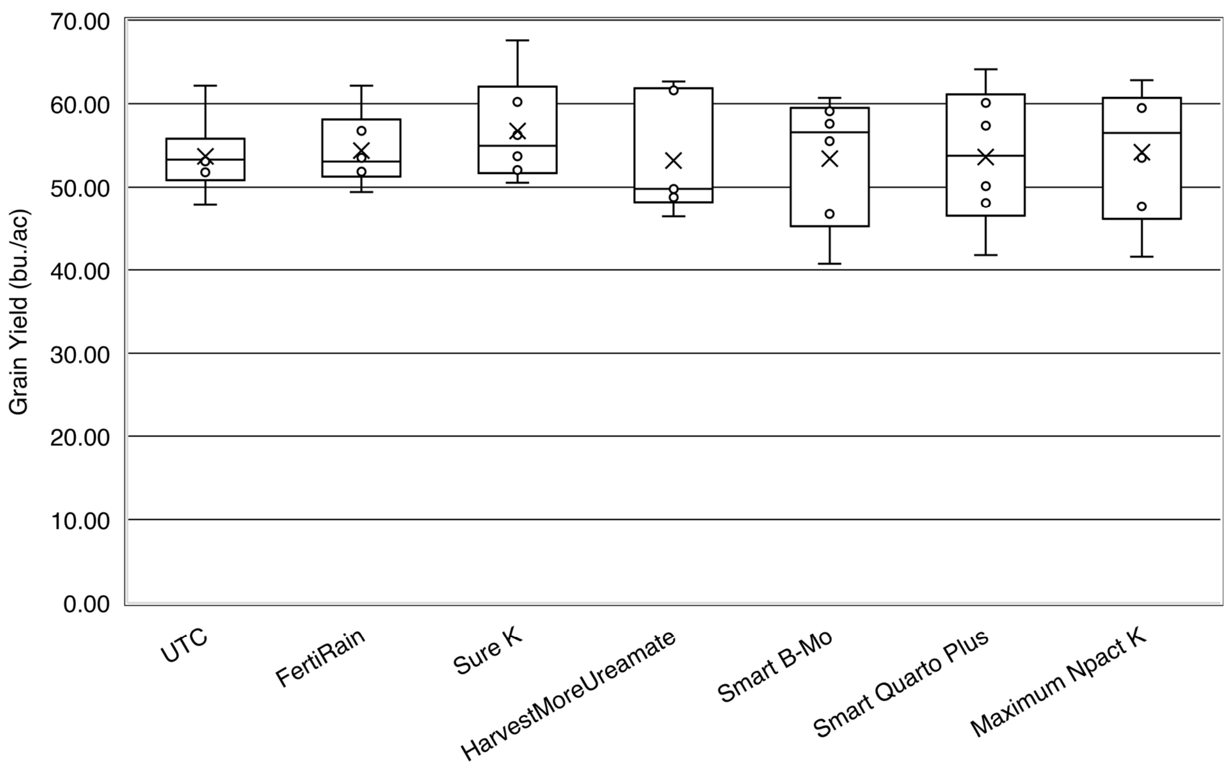

Fig. 1. Mean soybean yield (bu./ac) for each foliar nutrient product, 2019, Newport Extension Center, Newport, Ark. Boxes represent 50% quartile; "X" within each box depict means, and the line within the box is the mean value. UTC = untreated control.

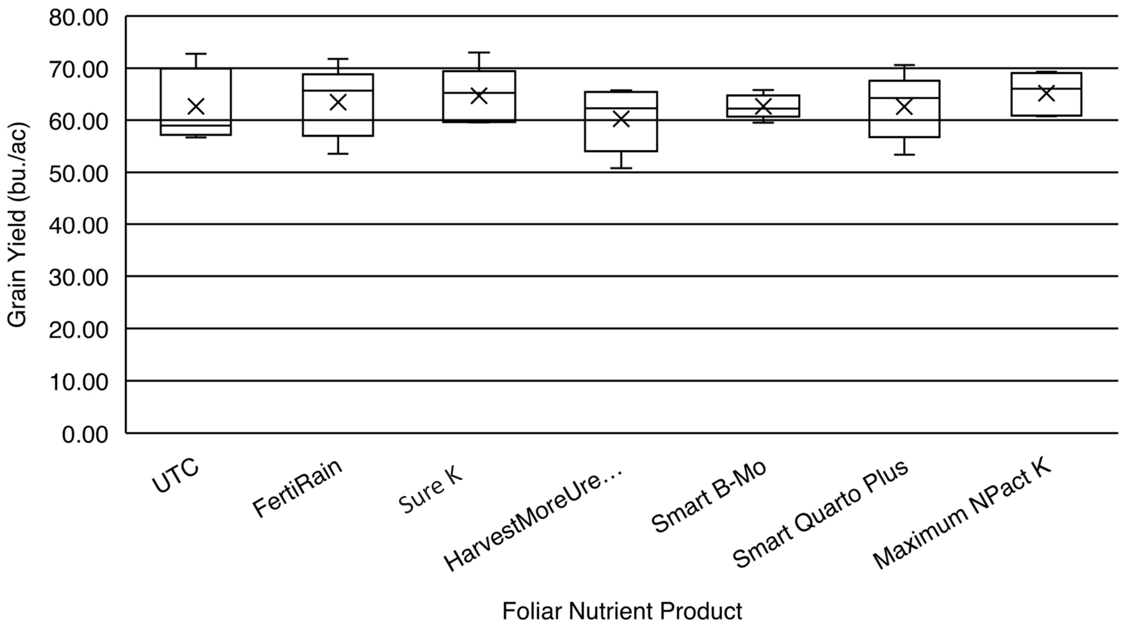

Fig. 2. Mean soybean yield (bu./ac) for each foliar nutrient product, 2019, Pine Tree Research Station, Colt, Ark. Boxes represent 50% quartile; "X" within the box depict means, and the line within the box is the median value. UTC = untreated control.

Soybean Response to Sulfur Fertilization

W.J. Ross,[1] J.P. Schafer,[1] and R.D. Elam[1]

Abstract

Two small-plot trials were conducted in 2019 at the University of Arkansas System Division of Agriculture's Newport Extension Center (NEC), Newport, Ark., and the Pine Tree Research Station (PTRS), Colt, Ark. to evaluate two sulfur (S)-containing fertilizers and one non-S nitrogen (N) fertilizer on soybean grain yield response. The same fertility trials were conducted in six other soybean-producing states in the U.S. Sulfur is considered one of the four essential macronutrients needed for soybean production. Due to increased crop removal and the lack of S from atmospheric deposition, S deficiencies are becoming more common in the soybean production region of the U.S. Results from the Arkansas trials showed no significant yield increase from the application of any of the fertility treatments. However, yield responses were not expected based on the results of the soil analysis.

Introduction

Sulfur (S) is one of the essential nutrient elements for soybean production, ranking behind N, phosphorus (P), and potassium (K) in importance. Reports of row crops with S deficiencies are increasing due to increased removal associated with higher crop yield and reduced input from atmospheric deposition. There is widespread concern that S could be the next limiting nutrient in soybean in the U.S. Sulfur is immobile within the soybean plant, so deficiency symptoms typically appear in the upper portion of the canopy in the newest growth. Atmospheric deposition previously accounted for a considerable amount of plant-available S, but this amount has significantly been decreasing due to the implementation of the Clean Air Act.

Much of the S in soil comes from the decomposition of soil organic matter. The form of S released from soil organic matter is a sulfate ion, which can be taken up by the soybean plant with its primary loss due to leaching.

Soils that are sandy and have low organic matter are at the greatest risk for developing S deficiencies. Under normal conditions, soybean often does not respond to S fertilization, but yield responses can be substantial in cases where soil S is deficient (Slaton et al., 2013).

In 2019, Arkansas collaborated with six other soybean-producing states on a multi-state project to evaluate the response of soybean to S fertilization. The objectives of this study were to 1) identify yield response in soybean to S fertilizer applications, 2) conduct economic analyses on the value of these applications, and 3) extend results to soybean growers through Extension platforms. This paper will only focus on the two locations where this test was conducted in Arkansas, and only report the yield responses of the fertilizer treatments tested in 2019.

Procedures

Trials were conducted at the University of Arkansas System Division of Agriculture's Newport Extension Center (NEC), Newport, Ark., and at the Pine Tree Research Station (PTRS), near Colt, Ark. in 2019. The soybean variety Asgrow AG46X6 (Bayer Crop Science; Leverkusen, Germany) was used for each trial, which was a 4.6 maturity group Roundup Ready 2 Xtend® soybean variety seeded at a rate 150,000 seed/ac. Plots consisted of four rows spaced 15 in. by 35-ft long. Trials were planted using a Precision Kincaid Vacuum Plot Planter (Kincaid Equipment Manufacturing; Haven, Kan) at both the NEC and PTRS on 7 July and 15 June, respectively. After planting, composite soil samples were taken for each plot. The average values of selected soil chemical properties are listed in Table 1. Fertilizer products and rates used for this study are listed in Table 2. A non-S N treatment was used to separate any S response from N-containing S products. Treatments were applied by hand immediately after planting. Management concerning irrigation, fertility, and late-season pest control closely followed recommendations from the University of Arkansas System Division of Agriculture's Cooperative Extension Service for soybean production. In each trial, soybean was irrigated as needed using overhead or flood irrigation at the NEC and PTRS, respectively. At maturity, plots were harvested, and the moisture content and the weight of the grain were determined. Grain yield was

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adjusted to 13% moisture and reported as bu./ac for each trial. Grain samples were collected from each plot for protein and oil analysis (data not shown).

Within each test, treatments were arranged as a randomized complete block design with five replications. Data were subjected to analysis of variance (ANOVA), using ARM 2020 (Gylling Data Management, Inc., Brookings, S.D.). When appropriate, mean separations were performed using Fisher's protected least significant difference method with α = 0.10.

Results and Discussion

Statistical analysis for soybean grain yield was conducted for each location, and mean soybean grain yields for each treatment are reported in Table 3. When compared to the untreated control, mean grain yields for all treatments were not statistically different. At the NEC location, the mean yield for the untreated control was 57.2 bu./ac, with treatment mean yields ranging from 51.5–56.4 bu./ac. Mean yields at the PTRS were from 64.0–69.7 bu./ac compared to the untreated control mean yield of 66.4 bu./ac.

The results from these trials are not surprising, due to the soil analysis indicating that both locations had S soil test values of 12 and 13 ppm at the NEC and PTRS locations, respectively. Soybean plants are very efficient at scavenging nutrients from the soil, and a response to additional S fertilizers would not be expected at these S soil test levels.

Similar to the Arkansas results, an analysis across all 19 locations from the seven states that conducted this study showed no significant differences in soybean grain yield. However, when individual locations were analyzed, five locations did have a significant yield difference due to fertilization treatment (data not shown). No treatment consistently increased yield and/or protein in every location.

Practical Applications

Results from this study showed that additional S fertilizers did not increase soybean grain yield in environments where these tests were conducted. However, some soils in Arkansas have tested very low in soil-test S (>5 ppm), and S deficiencies have been reported. Fields with a course soil texture and with low organic matter could potentially have soil-test S levels low enough to show S deficiencies. Routine soil testing will be required to identify these fields, and supplemental S containing fertilizers may be required.

Acknowledgments

The authors would like to thank the Arkansas Soybean Promotion Board for their funding of this research. We would also like to thank the personnel at the Newport Extension Center and the Pine Tree Research Station for the help and support of our fieldwork. Support was also provided by the University of Arkansas System Division of Agriculture.

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Table 1. Selected soil chemical property means (n = 50) from the 0–4 in. depth for the sulfur fertilization trials conducted in 2019.[a]

Location[a]	Soil Series	pH	P	K	Ca	Mg	S	Fe	Mn	Zn
			---				ppm			--
NEC	Dexter silt loam	6.4	116	125	767	129	12	189	195	4.4
PTRS	Calhoun silt loam	6.8	22	90	1568	234	13	296	106	2.1

[a]NEC = Newport Extension Center, Newport, Ark.; PTRS = Pine Tree Research Station, Colt, Arkansas.
[a]P = Phosphorus; K = Potassium; Ca = Calcium; Mg = Magnesium; S = Sulfur; Fe = Iron; Mn = Manganese; Zn = Zinc.

Table 2. List of sources and rates of sulfur-(S) and nitrogen-(N) containing fertilizers evaluated in 2019.

Product[a]	Application Rate	Supplied S	Supplied N
	------------------------lb/ac------------------------		
Untreated Control		0	0
Ammonium Sulfate	42	10	9
Ammonium Sulfate	83	20	18
Ammonium Sulfate	125	30	26
Gypsum	63	10	0
Gypsum	125	20	0
Gypsum	188	30	0
Urea	19	0	9
Urea	39	0	18
Urea	56	0	26

[a]Ammonium Sulfate (21% N; 24% S); Gypsum (16% S); Urea (46% N).

Table 3. Soybean grain yield response to sulfur (S) fertilizer products at the University of Arkansas System Division of Agriculture locations in 2019.

		Location[a]	
Product	Application Rate	NEC	PTRS
	lb/ac	--------Yield (bu./ac)--------	
Untreated Control		57.2	66.4
Ammonium Sulfate	42	55.4	64.3
Ammonium Sulfate	83	54.6	64.3
Ammonium Sulfate	125	56.4	66.0
Gypsum	63	54.7	65.4
Gypsum	125	56.2	64.0
Gypsum	188	51.5	65.8
Urea	19	54.7	65.8
Urea	39	56.3	69.7
Urea	56	53.9	66.6
		NS[b]	NS

[a]NEC = Newport Extension Center, Newport, Ark.; PTRS = Pine Tree Research Station, Colt, Arkansas.

[b]No statistical difference was seen between the untreated control and the S fertilizer treatments at $\alpha = 0.10$.

Classification of Soybean Chloride Sensitivity using Leaf Chloride Concentration of Field-Grown Soybean

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Abstract

Soybean [*Glycine max* (L.)Merr.] varieties are currently categorized as being chloride (Cl) includers, excluders, or a 'mixed' population. A more specific rating system is needed to differentiate between true Cl excluding varieties and a considerable proportion of varieties that may be mixed includer/excluder plant populations or a population of plants having multiple genes that influence Cl uptake. A field-based Cl monitoring program has been developed in conjunction with the Arkansas Soybean Performance Tests to provide a more detailed categorization of Cl tolerance in soybean varieties. A 1 to 5 rating system was developed and implemented on 196 varieties belonging to relative maturity groups 3.5 to 5.9 based on trifoliolate leaf-Cl concentrations included in the University of Arkansas System Division of Agriculture's Rohwer Research Station's location of the 2019 Arkansas Soybean Performance Tests. Trifoliolate-leaf samples were collected when soybean reached the R3 to R4 growth stage. Ratings of 1 (strong excluder), 2, 3 (intermediate), 4, and 5 (strong includer) were assigned to 61, 20, 38, 54, and 23 varieties, respectively. The detailed rating system provides producers with more information regarding the relative Cl tolerance of available soybean varieties

Introduction

Soybean varieties have historically been categorized as being chloride (Cl) includers, excluders, or a 'mixed' population. Cox (2017) showed that this three-class categorization and the method of assigning the trait leads to inaccurate categorization of some varieties and a more robust system is needed to accurately describe soybean tolerance to Cl. Abel (1969) concluded that a single gene-controlled Cl inclusion attributes of soybean, which contributed to the oversimplification of the Cl trait rating. Zeng et al. (2017) recently suggested that multiple genes may control Cl uptake by soybean adding complexity to an already poorly understood phenomenon. Research by Cox (2017) supports this hypothesis and highlights the varying levels of Cl inclusion and exclusion across a wide range of soybean varieties. Individual plants of some commercial varieties are mixed populations with some plants being strong includers with high Cl concentrations, some being strong excluders with very low Cl concentrations, and some plants having intermediate Cl concentrations. The large range of Cl concentrations in individual plants suggests that there may be multiple genes that regulate Cl uptake. Traditional methods of assessing Cl sensitivity of soybean varieties involve short greenhouse trials (completed before reproductive growth begins) with a limited number of plants (5–10), which limits the scope and applicability of the results. Our research objective was to examine leaf Cl concentration of commercial soybean varieties in a field production setting to assign a numerical Cl rating from 1 to 5, which provides a more robust classification of Cl tolerance.

Procedures

All varieties entered in the Arkansas Soybean Variety Performance trials were sampled at the University of Arkansas System Division of Agriculture's Rohwer Research Station in 2019. The trial included late-3, early-4, late-4, and 5 maturity group categories that ranged from 3.5–5.9. Soybean were planted on 15 May 2019 in a field having soil mapped as a Desha silt loam following corn (*Zea mays* L.) in the rotation. Soybean was planted on beds spaced 38-in. apart with each plot having 2 rows. Plots were furrow irrigated six times based on an irrigation scheduling program and managed using the University of Arkansas System Division of Agriculture's Cooperative Extension Service guidelines for furrow-irrigated soybean. Varieties were divided into three relative maturity (RM) ranges based on information provided by the originating company or institution; they are

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RM 3.5–4.4, RM 4.5–4.9, and RM 5.0–5.9. Soybean varieties with Xtend® technology were tested separately from varieties with all other herbicide technologies. Varieties were arranged as a randomized complete block design with three replications. Additional details of this trial, along with yield data, are available from Carlin et al. (2019). Varieties with known chloride tolerance (strong includer, strong excluder, and mixed) were included in each block of each maturity group and herbicide grouping to serve as a 'check' to provide a baseline response for relative comparison amongst varieties and locations within the field.

A composite sample comprised of one recently matured (top three nodes) trifoliolate leaflet (no petiole) collected from 10 individual plants in each plot and placed in a labeled paper bag when soybean was in the R3 to R4 stages. Plant samples were oven-dried, ground to pass a 2-mm sieve, and extracted with deionized water as outlined by Liu (1998).

Extracts were analyzed for Cl on an inductively coupled plasma atomic emission spectrophotometer.

The tissue-Cl concentration mean and standard deviation (SD) were calculated for each variety, and Cl concentration was ranked from lowest to highest. A numerical rating of 1 to 5 was assigned to each variety with 1 indicating a strong excluder (very low Cl concentration), 3 indicating a mixed population or a variety having an intermediate Cl concentration, and 5 indicating a strong includer variety with a very high Cl concentration. The ratings of 2 and 4 represented the gradient between the adjacent ratings. Breakpoints for specific categories in the numerical rating system shifted slightly from each soybean variety grouping to the next due to differences in the Cl concentrations of known check varieties that were included for standardization across the entire trial.

Results and Discussion

The mean leaflet-Cl concentrations ranged from 92 to 2248 ppm Cl across the 196 varieties sampled (Tables 1–3). In general, the standard deviation increased linearly as the mean Cl concentration increased, suggesting greater variability in the variety Cl concentrations for mixed and includer varieties. The late-3 and early-4 tests had the lowest total varieties, with 30 entries combined. Within this group, there were only two varieties that were identified as strong excluders in category 1 (Table 1). For this maturity group class (late-3 and early-4), half of the total varieties were classified as strong includers (either rated as 4 or 5). It appears that there are limited options available for producers who need Cl excluder varieties in the late-3 and early-4 maturity group range. For producers that may have areas prone to increased soil or irrigation water Cl concentrations, there was only one maturity group 3 variety that showed moderate Cl tolerance and was rated as a 2 with a mean Cl concentration of 706 and a standard deviation (SD) of 312 which suggests a wide range in the variability of the sampled blocks.

The late-4 class of varieties had the most overall entries with 128 and mean Cl concentrations ranging from 92–1615 ppm. Within this maturity group range, 52 varieties were identified as being strong excluders, which all fell within a narrow range of Cl concentrations (Table 2. 92–147 ppm Cl). There were only 5 varieties that fell within ranking 2 as moderate excluders. The vast majority of the entries into this late-4 class of varieties were identified as excluders, but the next largest group were the strong includers with 48 total varieties falling under Cl rankings of 4 or 5. These results indicate that there is an even distribution of Cl excluders and includers within the late-4 class of varieties allowing producers to choose from a wide variety of herbicide-tolerant traits and agronomic characteristics.

For the maturity group 5 class, there were a total of 38 entries, and the mean Cl concentration ranged from 119–1190 ppm across this group of varieties. Similar to the late-3 and early-4 class of varieties, there were a limited number of varieties (7) identified as strong excluders (Table 3), with the majority of the varieties falling in the rankings of 2–4 in terms of Cl tolerance. More than one-third of the varieties in the maturity group 5 class were identified as strong includers. It appears that there are limited varieties that have strong Cl exclusion ratings in the maturity group late-3, early-4, and 5 classes.

The very low standard deviation for varieties with a rating of 1 indicates that the composite sample Cl concentration variability among blocks was minimal for excluders, which would be expected based on research by Cox et al. (2018). The Cl concentration thresholds for assigning numerical variety rating will likely change from one year to the next as the fields used for the variety trials, rainfall amounts and timing, total irrigation water use, environmental factors, and irrigation water Cl concentrations may vary from year to year.

Practical Applications

Accurate variety Cl sensitivity ratings are important for growers that have irrigation water with high Cl concentrations or fields that may harbor Cl ions in the soil profile due to poor internal drainage from clayey soil texture or elevated sodium (Na) concentrations. The numerical rating system (1 to 5) based on the Cl concentrations of field-grown plants provide clear ratings that more accurately represent the variability of Cl uptake by soybean varieties than the three-tier rating system of includer, excluder, and mixed. One primary benefit of the new 1 to 5 rating system is that it provides higher resolution data for producers to use when selecting soybean varieties. Producers can now compare Cl tolerance with higher resolution across a wide range of herbicide tolerance and agronomic characteristics. If the producer is in search of a variety with specific traits and a high level of Cl tolerance, then this new ranking system can allow him to tease out differences in Cl tolerance amongst varieties that would traditionally be lumped together as "mixed." When comparing two varieties with similar traits, a producer can now differentiate between varieties traditionally classified as mixed and select a variety rated as 2 over one rated as 4, knowing that there are distinct differences in the Cl tolerance of those two varieties. The new rating system will especially benefit growers that farm with marginal irrigation water high in Cl concentration.

Acknowledgments

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Table 1. Mean and standard deviation (SD) leaflet chloride (Cl) concentrations and preliminary rating for Late Group 3 and Early Group 4 varieties (3.5–4.4) as determined from field-grown plants at the University of Arkansas System Division of Agriculture's Rohwer Research Station Soybean Variety Performance trial in 2019.

Variety[a]	Mean	SD	Rating[b]	Variety[a]	Mean	SD	Rating[b]
	ppm	ppm			ppm	ppm	
Local Seed X4301XS	213	25	1	Mission A4448X	612	580	3
Progeny 4265RXS	242	61	1	Eagle 4460RYX	619	750	3
Armor 44-D92	333	243	2	Asgrow 43X0	708	794	3
Armor 42-D27	544	389	2	MorSoy 4447 RXT	837	378	3
Pioneer P42A96X	545	584	2	Progeny 4444RXS	842	169	3
S13-3851C	706	312	2	GoSoy 44GL18	927	124	3
DG 45E23	798	118	2	REV 4310X	985	441	4
Dyna S42EN89	810	37	2	Progeny 4255RX	987	334	4
Progeny 4241 E3	815	17	2	Local Seed 3976X	1175	859	4
				Credenz 3929GTLL	1165	256	4
				Progeny 4291LR	1233	141	4
				S13-2743C	1459	146	4
				NK S39-G2X	1225	189	5
				AgriGold G4440RX	1458	263	5
				Dyna S41XS98	1481	950	5
				NK S44-C7X	1526	183	5
				Credenz 4280X	1575	873	5
				Asgrow 42X9	1737	1213	5
				Credenz 3841LL	1860	895	5
				Local Seed 4487XS	2040	875	5
				Credenz 4222LL	2248	535	5

[a] Abbreviation key: DG = Delta Grow; Dyna = Dyna Gro; Eagle = Eagle Seed; GoSoy = Stratton Seeds; REV = Terral Seed; S = University of Missouri.

[b] Varieties may have varying leaflet chloride concentrations within the same numerical rating due to blocking within the field. A rating of 1 means strong excluder, and a rating of 5 means strong includer.

Table 2. Mean and standard deviation (SD) leaflet chloride (Cl) concentrations and preliminary rating for Late Group 4 varieties (4.5–4.9) as determined from field-grown plants at the University of Arkansas System Division of Agriculture's Rohwer Research Station Soybean Variety Performance trial in 2019.

Variety[a]	Mean	SD	Rating[b]	Variety[a]	Mean	SD	Rating[b]
	ppm	ppm			ppm	ppm	
Armor X46D09	92	18	1	DG 4977LL/STS	328	71	2
MorSoy 4846 RXT	96	15	1	Dyna S49EN79	409	368	3
Asgrow 46X6	96	13	1	DG 47E25	460	248	3
Pioneer 48A99L	96	9	1	Progeny 4682 E3	503	332	3
Pioneer 48A60X	98	11	1	Hefty H47E0	507	438	3
DG 48X45	104	24	1	Dyna S46EN29	545	206	3
Asgrow 46X0	104	4	1	DG 48X05	563	253	3
Mission A4618X	105	13	1	Credenz 4540LL	564	546	3
Eagle 4680RYX	107	25	1	R16-259	584	103	3
Armor X47D18	107	14	1	Credenz 4649LL	594	747	3
USG 7470XT	107	13	1	MorSoy 4706 RXT	594	225	3
Pioneer 46A57BX	107	14	1	USG 7480XT	596	184	3
DG 46X65	108	13	1	Taylor EXP 47-90	622	90	3
AgriGold G4815Rx	108	2	1	Hefty H48E0	656	377	3
Dyna S46XS60	109	34	1	Progeny 4833 E3	668	166	3
Armor X49D67	109	4	1	DG 46E29	668	484	3
DG 48E49	109	10	1	Armor X47D86	698	306	3
Armor X47D85	112	11	1	Local Seed X4801X	763	197	3
Progeny 4620RXS	112	24	1	Armor X45D51	796	209	3
LGS 4845RX	112	28	1	USG 7496XTS	802	321	3
Armor X48D25	116	12	1	REV 4679X	807	133	3
Local Seed X4901X	117	10	1	Progeny 4670RX	824	409	3
Asgrow 47X0	118	33	1	REV 4940X	851	186	3
Progeny 4821RX	119	33	1	Credenz 4770X	862	214	3
USG 7478XTS	119	24	1	USG 7499ET	718	152	4
USG 7489XT	120	58	1	Credenz 4938LL	741	531	4
Dyna S47XT20	121	21	1	DG 48E39	750	243	4
Local Seed 4798X	121	13	1	DG 48E10	768	185	4
Progeny 4620RXS	112	24	1	S14-151138R	780	350	4
LGS 4845RX	112	28	1	Progeny 4891 E3	790	98	4
Armor X48D25	116	12	1	R16-253	810	407	4
Local Seed X4901X	117	10	1	Progeny 4710 E3	821	491	4
Asgrow 47X0	118	33	1	Hefty H48E9	841	179	4
Progeny 4821RX	119	33	1	USG 7460ET	842	307	4
USG 7478XTS	119	24	1	GoSoy 482E18	855	259	4
USG 7489XT	120	58	1	LGS4931RX	890	237	4
Dyna S47XT20	121	21	1	AGS GS49X19	895	321	4
Local Seed 4798X	121	13	1	DM Experimental	898	252	4
GoSoy 49G16	122	20	1	Armor X48D88	910	178	4
Dyna S48XT56	122	60	1	Credenz 4820LL	910	11	4
Dyna S45XS37	125	25	1	Progeny 4999RX	913	112	4
Local Seed X4601XS	126	5	1	Credenz 4539GTLL	938	746	4
NK S49-F5X	130	52	1	DG 46X25	942	274	4
AgriGold G4579RX	130	51	1	Local Seed X4501X	947	411	4
REV 4927X	131	8	1	Local Seed 4889XS	950	169	4
Asgrow 48X9	132	57	1	Progeny 4525 E3	969	117	4
Local Seed 4565XS	133	13	1	DG 49E29	971	497	4
Hefty H46X0S	139	23	1	Local Seed X4503GTLL	982	122	4
Petrus 4916 GT	139	39	1	Credenz 4570X	988	156	4
Credenz 4649LL	143	23	1	LGS 46682RX	1013	47	4
Progeny 4816RX	146	22	1	Eagle 4840RYX	1030	246	4
Taylor EXP 48-80	147	57	1	Dyna S45XS66	1034	325	4
Dyna S49XT70	153	81	2	Mission A4950X	1038	532	4
LGS 4899RX	168	84	2	Armor X46D30	1042	441	4
Progeny 4775 E3S	283	296	2	Credenz 4600X	1050	385	4
USG 7480ET	293	322	2	DM 47X01	1086	575	4

Continued.

Table 2. Continued.

Variety[a]	Mean	SD	Rating[b]	Variety[a]	Mean	SD	Rating[b]
	ppm	ppm			ppm	ppm	
DG 49X15	1098	190	4	GoSoy 46GL18	1187	311	5
Dyna S49XT39	1100	374	4	R15-2422	1241	401	5
AgriGold G4605RX	1101	262	4	GoSoy 481E19	1256	242	5
Asgrow 49X9	1124	186	4	Local Seed 4677X	1354	581	5
Progeny 4851RX	1241	553	4	AGS GS48X19	1361	272	5
DM 48E01	1017	272	5	Progeny 4565LR	1547	894	5
Credenz 4918LL	1028	206	5	Local Seed 4583X	1573	471	5
Local Seed X4701E	1030	471	5	GoSoy 48C17S	1615	944	5

[a] Abbreviation key: AGS and GoSoy = Stratton Seeds; DG = Delta Grow; Dyna = Dyna Gro; DM = DONMARIO; Eagle = Eagle Seed; LGS = LG Seeds; R = University of Arkansas System Division of Agriculture; REV = Terral Seed; S = University of Missouri; USG = UniSouth Genetics, Inc.

[b] Varieties may have varying leaflet chloride concentrations within the same numerical rating due to blocking within the field. A rating of 1 means strong excluder, and a rating of 5 means strong includer.

Table 3. Mean and standard deviation (SD) leaflet chloride (Cl) concentrations and preliminary rating for maturity group 5.0–5.9 varieties as determined from field-grown plants at the University of Arkansas System Division of Agriculture's Rohwer Research Station Soybean Variety Performance trial in 2019.

Variety[a]	Mean	SD	Rating[b]	Variety[a]	Mean	SD	Rating[b]
	ppm	ppm			ppm	ppm	
Dyna S56XT99	119	23	1	R16-378	616	191	3
Armor 55-D57	128	27	1	Progeny 5211 E3	653	204	3
Progeny 5554RX	129	14	1	Asgrow 52X9	686	213	3
R13-13997	129	33	1	DG 54X25	690	68	3
R15-1587	132	24	1	Progeny 5016RXS	732	160	3
Progeny 5688RX	138	11	1	Progeny 5170RX	734	39	3
Local Seed 5588X	145	23	1	Credenz 5299X	747	195	3
R14-1422	158	48	2	Credenz 5150LL	788	188	3
R16-39	161	49	2	GoSoy 512E18	790	71	3
R16-2456C	177	27	2	Local Seed 5386X	790	102	4
GoSoy 50G17	185	87	2	Eagle 5155RYX	790	128	4
R13-818	186	116	2	AgriGold G5000RX	796	41	4
R16-2547	194	31	2	DG 52E22	804	227	4
DG 5585RR2	196	48	2	Asgrow 53X0	852	274	4
R16-1445	259	135	2	R13-14635RR	865	325	4
				Dyna S52X39	872	151	4
				Progeny 5252RX	874	351	4
				Progeny 5335RX	897	101	4
				Armor 51-D71	907	293	4
				DG 52X05	968	217	4
				Hefty H51E9	1070	229	5
				Armor 51-D77	1164	115	5
				Local Seed 5087X	1190	129	5

[a] Abbreviation key: DG = Delta Grow; Dyna = Dyna Gro; Eagle = Eagle Seed; GoSoy = Stratton Seeds; R = University of Arkansas System Division of Agriculture.

[b] Varieties may have varying leaflet chloride concentrations within the same numerical rating due to blocking within the field. A rating of 1 means strong excluder, and a rating of 5 means strong includer.

Soybean Science Challenge: Growing Beyond Our Borders

J. C. Robinson[1] and D. Young[1]

Abstract

The Soybean Science Challenge (SSC) continues to support Arkansas STEM (science, technology, engineering, and mathematics) educational goals, is aligned with the Next Generation Science Standards (NGSS), and engages high-school students in active learning and the co-creation of knowledge through support of classroom-based lessons and applied student research. The SSC educates and engages high school science students and teachers in 'real-world' Arkansas specific soybean science education through original NGSS aligned curriculum in 7E and Gathering Reasoning and Communicating (GRC)-3D format and a continuum of educational methods which include: teacher workshops, online and virtual live stream education, teacher-focused conference booths, community gardens, personal mentoring, student-led research and corresponding award recognition, and partnerships with state and national educators, agencies and the popular media. The COVID-19 global pandemic altered the educational landscape in 2020. The new educational environment has seen an increase in virtual classrooms, online courses, and interactions with Zoom©. The Soybean Science Challenge, by nature of its existing design and methodology, was amid these methods by launching online Next General Science Standards Aligned GRC-3D and 7E lesson plans for teachers, expanding the online course, and adding additional virtual field trips to the list on the Soybean Science Challenge website. Through the SSC, teachers now have access to a plethora of educational instructions that bring real-world agricultural critical thinking both into the classroom, and homes of students. The SSC has learned that not only Arkansas teachers and students have benefited from these additional resources but teachers and students from other states as well.

Introduction

The Soybean Science Challenge (SSC) has been active and growing since its inception in 2014. The SSC has always used a 'high tech' approach through online classes, virtual field trips, virtual mentoring, and communication through emails and Zoom. It has also balanced this with 'person to person' interactions at teacher workshops, conventions, and science fairs. The goal of the Soybean Science Challenge is to support a higher level of student learning and research regarding the importance of soybean production and agricultural sustainability in the state of Arkansas. For this to happen, the SSC has worked tirelessly at developing relationships with Arkansas' teachers and by supplying them with cutting edge educational tools and the knowledge they need, through online teacher in-service and face to face workshops, to use them effectively in the classroom. The Soybean Science Challenge has also worked with students through mentorship and the online course. The real question is, "have we made a difference, especially in light of the COVID-19 pandemic that has closed schools?"

Procedures

The Soybean Science Challenge is foremost, an instructional tool for teachers and a real-life critical thinking program for students (Ballard and Wilson, 2016). One of the flagships of this program is the SSC Cash Awards given out to soybean-related science fair projects at the regional science fairs, the FFA AgriScience Fair, and the Arkansas State Science Fair. For students to enter the Soybean Science Challenge Award competition at these fairs, students must submit for judging a project that is either soybean-based or an agriculturally sustainable project and have passed the six-module SSC online course. Students must receive at least 80% or better on each quiz before they can progress to the next module. Pre- and post-course quizzes qualitatively measure student learning. Student research for these projects is supported by vetted science-based resources, the soybean seed store, and researcher mentoring for students interested in projects that require a higher level of exploration than available at the local high school.

To determine the outcome/impact evaluation of the SSC, the numbers of students enrolled in the SSC online course and the fairs over the last three years, plus usage of resources

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was tabulated and noted in Table 1. This includes the spring of 2020, having just finished the nine science fairs across the state. Community Gardens are still being advertised, and will not be finished for 2020 until June, leaving the Community Garden data incomplete. The online course does not close until June 2020, and will most likely increase.

Results and Discussion

A series of key factors contribute to the evidence of real learning-based results in the Soybean Science Challenge Program. For 2018-2020, the Soybean Science Challenge Pre-test, student learning, and knowledge averaged 33.4%; however, the post-test average was 85.5%, a marked increase in student knowledge of soybean as a result of taking the online course. Another factor is the overall increase in students taking and completing the course. The total for 2014 through March 2017 was 218 students. The current total is 570 students, over double the number of students in the same number of years, with almost 70% of those students completing the course with an 80% or higher total score. This is a strong indication that the course is successful at teaching students about soybean.

Along with the online course, the Soybean Science Challenge student research awards presented at Arkansas regional and state science fairs played a major role in increasing student knowledge about the sustainability and impact of the Arkansas soybean industry. Each year from 2017–2020, the number of projects has increased, and the state fair had so many projects entered in 2019 (15 projects) that project coordinators decided to increase the award number to three for the 2020 science fair year (first place, second place, and honorable mention). Despite COVID-19 issues and challenges, SSC had 11 projects enter the virtual state science fair. In order to judge students, judges were provided an abstract and a video of each student researcher explaining their project. In 2019, one regional Soybean Science Challenge winner was awarded an International Science and Engineering Fair (ISEF) Finalist position. This award is only given to those who receive the 'Best in Fair' awards. For 2020, three SSC winners were awarded the coveted ISEF Finalist position at their respective fairs. This demonstrates an increase in the quality and rigor of projects competing for the Soybean Science Challenge award in the area of soybean and agricultural sustainability and suggests that the Soybean Science Challenge is a successful program for high school students by providing student information and education to reach a higher level of research.

Through this program, the Arkansas Soybean Promotion Board (ASPB) invested $16,800 in student research awards for science projects with a soybean-related focus. This recognition raised the educational profile about soybean in Arkansas and the importance of ASPB's goal of supporting effective youth education emphasizing agriculture. A total of 73 individual projects were judged with 29 student awards presented on behalf of the ASPB.

The Soybean Science Challenge has also chosen these last three years to focus on helping teachers bring critical thinking into the classroom through agriculture. In 2016, science teachers throughout the state were required to start phasing in the new Arkansas State Science Standards (based on the NGSS) into their classrooms. This included lessons to be written in the new GRC-3D format. To this end, the SSC has designed and developed seven different soybean and/or agricultural-based lessons written in both the standard 7E Format and in the new GRC-3D Format for teacher use. The Soybean Science Challenge has also produced four different virtual field trips (VFT)with NGSS Aligned manuals for teachers to use. All are available in paper form and online at the soywhatsup.com website. Over 100 lesson plans and VFT lesson manuals have been distributed at conferences, workshops, and STEM days. Lessons and the free resource guide were also distributed at the National Ag in the Classroom Convention in Little Rock, June 2019. Many AG teachers from across the nation were thrilled to learn there is an online source of NGSS Aligned lessons they can use in their classroom.

With the advent of COVID-19, the overarching question was, 'During this difficult time, will the Soybean Science Challenge Program be an asset to students and teachers?' All schools have been closed since the end of March 2020, and teaching is done primarily via Zoom© or computer-based. Most of the science fairs chose to host 'virtual' fairs, which required students to submit videos for their interviews, which can be a daunting task. To see the success of the SSC during this pandemic, one only needs to look at the numbers. The number of students in 2019–2020 who have currently taken the course is 163 with 106 having completed the course with an 80% or higher. The SSC had 27 entries for this year's science fairs, a record high, especially considering the added video component, with three of the regional winners being awarded the ISEF Finalist position, showing an increase in the caliber of projects judged this year. The SSC's online educational tools have shown to be a strong asset in helping teachers be successful in the virtual classroom, not just in Arkansas but in other states as well.

Practical Applications

The Soybean Science Challenge makes agricultural sustainability relevant and meaningful for Arkansas high school students and helps teachers teach through real-world critical thinking lessons and virtual field trips. The success of this project shows that students are up to the task of handling real-world, real-time problems that require critical thinking while being exposed to the world of agriculture in ways they never expected to see. Students now understand that agriculture is a STEM field that needs highly educated youth to take the reins of the future from our current professionals. They are learning that agriculture is more than farming; it is a technical career that offers them the opportunity to make a difference on a worldwide scale. The Soybean Science Challenge's goal is succeeding, helping youth to discover the world of agriculture.

Acknowledgments

This educational project was supported by the University of Arkansas System Division of Agriculture and soybean check-off funds administered by the Arkansas Soybean Promotion Board.

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Table 1. Year-to-date Soybean Science Challenge online course enrollment: 1 April 2019 –31 March 2020.

Student Enrollment	Current Student Course Completion	Average Student Pre-Test Score	Average Student Post-Test Score	Teacher In-Service Enrollment
163	106	34.4	84.7	9

Table 2. Soybean Science Challenge products, audience, activities and impact 2019–2020.

Products	Target Audience	Activities and Impact
Soybean Science Challenge Online Course – Student	9-12th grade students	**163** Students enrolled; **106** completed
Soybean Science Challenge Online Course – Teacher In-Service (7 Hrs.)	science teachers	**9** Teachers enrolled; **1** completed
Soybean Science Challenge Online Course – Teacher Resources	science teachers	**14** Users
Partnered with 7 regional science fairs, the FFA AgriScience Fair and the Arkansas State Science Fair. Attended and judged nine Arkansas science fairs.	science teachers/students science fairs	**20** articles published or posted in newspapers or on websites; **27** individual student projects with **11** student awards; Totaling **$6,350**
It's Never Too Early to Plant the Seeds of Science Education – Soybean Science Challenge Announcement Flyers (2)	Science Teachers/Students	Released multiple times to ARSTEM List Serve; ASTA List Serve, Ark. Educational Cooperatives, personal emails; mailed to over **500** Arkansas Science and AG Teachers for 2019-2020
Participated in Earth and Environmental Sustainability Field Trip, UA-Fayetteville September 2019	9-12th grade science teachers/students	Handed out SSC materials to **over 100 students and teachers,** including edible edamame, seeds, and brochures. Teachers got gift bags.
Participated in a Soybean Science Challenge Booth and implemented an SSC lesson related workshop at the National AG in the Classroom National Conference in Little Rock, June 2019	3-12th grade science teachers, AG teachers, FFA Advisors, and County Agents	Handed out Soybean Science Challenge materials to **over 500** teachers. Research manuals, SSC brochures, SSC NGSS aligned lesson plans, edamame seeds, and SSC brochures were handed to all booth visitors. Gift bags were handed out to the 15 teachers who attended the SSC workshop.
Implemented an all-day Soybean Information day at Guy Perkins Elementary School in April 2019.	K-6th grade science teachers and students	Handed out soy crayons/coloring books, activity books, pens, pencils, and edamame seeds to **over 100** teachers and students.
Soybean Science Challenge Brochure	9-12th grade high school students/ teachers	ARSTEM List Serve; ASTA List Serve; Ark. Educational Cooperatives; personal emails; SOYWhatsUP CES web page; conferences; field trips, STEM days, and teacher workshops
Soybean Science Challenge Seed Store announcement	high school students/teachers	ASTA List Serve; Ark. Educational Cooperatives; personal emails; SOYWhatsUP CES web page; workshops; teacher conferences; mailed to over **500** Arkansas Science and AG Teachers.
Soybean Science Challenge Seed Packets	science teachers/students	Over **500** distributed at Educational Conferences and other Soybean Science Challenge events such as 'Thunder Over the Rock,' UA-Fayetteville, Guy-Perkins, Co-op workshops, Farm Bureau Convention, and National Agriculture in the Classroom.
Science Fair workshops at local STEM centers and Co-ops throughout the state	science teachers	Over 30 teachers have participated in the Soybean Science Challenge Arkansas Department of Education approved workshops throughout the state this year.
Soy Science Scholars Booklet; Soybean Science Challenge Progress	ASPB; CES	Mailed to ASPB and CES

Continued.

Table 2. Continued.

Products	Target Audience	Activities and Impact
Soy What's Up? Flier on resources found on the CES Soybean Science Challenge webpage – www.uaex.edu/soywhatsup	science teachers/students	ASTA List Serve; Ark. Educational Cooperatives; personal emails; SOYWhatsUP CES web page; conferences workshops; STEM days, mailed to **over 500** Arkansas science and agriculture teachers.
Media Coverage of Soybean Science Challenge Events	science research, agriculture educators, and general public	**15** articles in newspapers, magazines, and other publications
SSC Direct Contacts regarding online courses/events/activities	science teachers/ students, other partners, i.e., ADE, STEM, Educational Coops	**Over 10,000** direct contacts through Constant Contact, ARSTEM Science List Serve, Arkansas Educational Cooperatives, and individual science teacher/student emails.
Developed/produced 4 Soil and Water Conservation research-based Virtual Field Trips with NGSS Aligned Lesson Manuals.	Science Teachers/Students	**45** schools participated; over **1,100** youth from diverse backgrounds; over **20** CES faculty/staff participated; over **45** questions fielded by CES faculty/staff; Videos and Teachers Guide posted on SOYWhatsUP CES webpage. Handed out **over 100** different lessons at conventions, workshops, STEM days, science fairs, and via email to interested teachers.
Developed/produced seven different Soybean based NGSS Aligned (in 7E and GRC-3D Format) lesson plans for classroom use.	science teachers/ students	**45** schools participated; over **1,100** youth from diverse backgrounds; over **20** CES faculty/staff participated; over **45** questions fielded by CES faculty/staff; Videos and teachers guide posted on SOYWhatsUP CES webpage. Handed out **over 100** different lessons at conventions, workshops, STEM days, science fairs, and via email to interested teachers.
Soybean Science Challenge Community Gardens	science teachers/students, County Agents, Master Gardeners, community garden participants	**40 gardens** across the state for 2020. Advertising through Constant Contact, email, and on the soywhatsup.com website, reaching over 1,000 contacts.

Online Nematology Course

J. C. Robinson[1] and A.E. Lockhart[1]

Abstract

There are many types of nematode species that have been found in soybean. However, there is very little that is commonly known about the damage caused by nematodes in Arkansas. The most common nematodes found in other commodities have been detected on soybean, but the nematodes are not always found to be at a damaging level. Nematode symptoms in soybean vary widely with nematode species. Foliar diseases in soybean have very visible symptoms, as do root symptoms. Nematode symptoms in soybean are not as visibly detectable. A nematode problem is rarely detected based on foliar symptoms. Components of the online course are peer-reviewed, pilot tested, and launched to the general public. The goal of this course is to educate the University of Arkansas System Division of Agriculture's Cooperative Extension Service County Extension Agents, students, growers, crop consultants, and others on the topics of how to properly identify and collect disease samples, how to recognize symptoms, identifying nematodes, proper soil sampling, how to prepare and submit samples, how to read the reports with testing results, and how to make appropriate management and treatment recommendations.

Introduction

The current interest in the flexibility of online learning and the growing popularity of online courses offer an opportunity to teach a larger student population across occupations and knowledge levels. It seems timely to develop an online course that meets a need statewide about nematology and their significance as crop pests that can be detrimental to yields and profits. The University of Arkansas System Division of Agriculture's Cooperative Extension Service (CES) can help educate the farming and non-farming public about nematodes, which can have devastating production and economic impacts on soybean production in the state. The Cooperative Extension Service objectively presents research-based information on identifying and managing nematodes, enabling people to make more informed decisions. A key audience that needs access to research-based, accurate information are farmers and personnel that work in the agriculture industry. Researchers from CES and the University of Arkansas System Division of Agriculture's Agricultural Experiment Station (AES) have researched-based curricula to share with the public. Effective design for such training maximizes the likelihood that producers and agriculture industry personnel will use the information learned in the course.

An online course was developed and pilot-tested by members of the general public and CES and AES personnel. Pilot-testers identified needed changes and technical issues, as well as made suggestions to improve the course. These changes and suggestions were addressed before the course launch. The module titles in the course were: 1) introduction; 2) nematode anatomy; 3) nematodes in field crops; 4) economic impact; 5) sampling; and 6) nematode management strategies. The course and lessons are viewable on numerous devices, including PC, Mac, iPad, iPhone, Android mobile devices, and tablets. The interactive modular course was developed using accepted adult-learning methods and format.

Procedures

Objective one for this project was to develop a standard six-week short-course with an emphasis in nematology, focusing on recognizing the symptoms, proper sampling, preparing, and submitting the samples, reading reports, and making production recommendations. Course components include videos, interactive lessons, assignments, discussion boards, quizzes, and assigned reading.

Course components were developed in Camtasia© video editing software, Adobe© PDF, and Articulate© Storyline. The versatility of course components affords the opportunity for copying the course into several different online course management systems (i.e., Blackboard©, Moodle©, etc.), in anticipation of organizations or higher education institutions adopting the course as part of their training, curriculum, and professional development efforts. The course developers used accepted adult-learning methods and online learning best practices. Factual content was provided by our science

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cooperators, who currently teach nematology and disease symptomology principles, and modified the content for an online platform. The modules cover nematology, symptom identification, testing methods, and best practices for control strategies. Learners completing the course are challenged by appropriate exercises to test knowledge gained during the course and overall understanding at completion. A course completion certificate and continuing education credit can be issued upon successful completion.

The second objective for this project was to peer review the beta version of the course, then pilot-tested by selected learners, county agents, farmers, and others.

Feedback was used to modify the course as needed then a final version was launched on the University of Arkansas System Division of Agriculture COURSES websites. Course analytics are collected and analyzed periodically after launch and reported to the Board.

Results and Discussion

Course evaluations explore if respondents agree or strongly agree that the course content is appropriate for online learning, that the content was engaging, and that the course was well organized and easy to follow. Respondents will also indicate whether or not their knowledge increased in the following areas of nematology: basic understanding of nematodes, nematode anatomy, nematodes in field crops, the economic impact of nematodes, nematode sampling, and nematode management strategies.

The course is hosted on a Moodle platform accessible via the Internet http://courses.uaex.edu/login/index.php. The course requires a user id and password, available to anyone who creates an account. New users must create an account first, and instructions are on the login webpage. The content was provided by our science cooperators. The content was adapted for the general public and adult learner levels of understanding. In order to appeal to and engage all learning types (visual, auditory, and kinesthetic), interactive narrated lessons, videos, and print materials were developed to be used throughout the course. The modules specifically address an introduction to nematodes, nematode anatomy, nematodes in field crops, economic impact of nematodes, nematode sampling, and nematode management strategies —using soybean as the model crop.

Practical Applications

Every year, many hours of effort and money are wasted based on poorly collected samples or samples that are submitted for testing that can never be used. The knowledge shared in this course could help improve sampling and sample submission. The reports that are created with sample test results can be confusing and overwhelming. This course describes, provides examples, and instructs participants on how to read and act on the sample results and reports provided. Research and science-based recommendations are also a key component of this course, based on the sample and testing results discussed in the course.

The current interest in online information by the public and the growing popularity of free online courses offer an opportunity to teach a large audience the facts about nematodes, nematode testing, and best practices. This course is knowledge gain for growers and support personnel.

Acknowledgments

This educational project was supported by the University of Arkansas System Division of Agriculture and soybean check-off funds administered by the Arkansas Soybean Promotion Board.

Increasing Nutrient Utilization of Soybean Meals for Largemouth Bass Through the Combined Use of Fermentation and Prebiotics

M.N. Jones[1] *and R.T. Lochmann*[1]

Abstract

Juvenile Largemouth Bass (*Micropterus salmoides*) weighing an average of 0.14 oz were stocked into eighteen 50-gal tanks for a feeding trial. Six diets containing different protein sources (regular or fermented soybean meal, or fish meal), with or without a dairy/yeast prebiotic, were fed twice daily to satiation to triplicate groups of fish for 8 weeks. There were noticeable differences in feed intake, and both soy diets were less palatable than the fish meal diet. As a result, feed intake and growth were lower in soy treatments. Survival was also compromised in both soy diets compared to the control, but the reason was not apparent. There were no significant effects of the prebiotic on performance, regardless of protein source. There were no differences in hematological or immune parameters. Hepatosomatic index (HSI) was higher in the fish fed the fish meal and regular soybean meal diets compared to the diet with fermented soy.

Introduction

Largemouth Bass (*Micropterus salmoides*) is a commercially valuable sportfish raised on 195 farms throughout the United States of America (an increase from 176 farms in 2013). Most of the fish that are being sold are food size or market size fish (USDA NASS, 2018). Largemouth Bass is a carnivorous fish species that perform well when fed diets with fish meal. Fish meal is highly digestible and has a high-fat content, but can be an expensive product at $1399.61/ton versus $333.13/ton for soybean meal (Sampaio-Oliveira and Cyprino 2008; Index Mundi 2020). Soybean is high in protein and is used extensively in many aquaculture feeds, but they have antinutritional factors such as trypsin-inhibitor and indigestible carbohydrates (Refstie et al., 2000).

The introduction of prebiotics and probiotics to aquaculture diets can increase feed efficiency, which could lead to better weight gain and lower feed costs. PepSoyGen™ (Nutraferma, North Sioux City, S.D.) is a soybean meal product fermented with *Aspergillus* spp. and *Bacillus* spp. (Barnes et al. 2014; Nutraferma, 2020). The microbial species used to produce PepSoyGen™ remain alive in the final product and can provide probiotic effects (Gatesoupe, 1999; Burr et al., 2005). Grobiotic-A®, the prebiotic used in this study, is a mixture of partially autolyzed brewer's yeast, dairy ingredient components, and dried fermentation products (GroBiotic®-A, International Ingredient Corporation, St. Louis, Mo.) (Merrifield, 2010). The addition of prebiotic can influence immune parameters, response to stress, and growth (Merrifield, 2010; Merrifield and Ringo, 2014).

The objective of the current study was to evaluate the effects of PepSoyGen™ and regular soybean meal (dehulled, solvent-extracted, 48% protein) with or without prebiotic compared to a fish meal control diet on growth performance and immune function of Largemouth Bass.

Procedures

Feed-trained Largemouth Bass juveniles were obtained from Dunn's Fish Farm in Brinkley, Ark. They were acclimated to test conditions for 2 weeks before initiating the trial. Twenty-five Largemouth Bass, weighing 0.14 oz each, were stocked into eighteen, 50-gal tanks supplied with dechlorinated municipal water. The culture system was a recirculating system kept at 80.6 ºF. Continuous aeration was provided to each tank, and the water flow rate was approximately 0.5 gal/min. The six experimental diets were assigned to the tanks, with three replicates for each diet. The Largemouth Bass were monitored for 8 weeks, weighed every 2 weeks, and fed twice daily to satiation. After the final weights were measured, the fish were fed once daily to satiation for one week before samples were taken for health assays. This was done to reduce the effects of stress on the analysis.

Six experimental diets were formulated that met or exceeded the known nutrient requirements of Largemouth Bass, with 46.4% protein and 22.3% lipid (Table 1). The diets included practical ingredients commonly used in commercial Largemouth Bass diets. The PepSoyGen™ diet had no fish meal but did include regular soybean meal. A similar diet was formulated to include 2% prebiotic for each, replacing

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the cornstarch. The diet ingredients were pressure cooked to simulate an extruded diet.

Ingredients and diets were analyzed for protein, dry matter, and ash content using standard methods (AOAC, 1995). Total lipids from the diets were extracted and quantified using the chloroform/methanol procedure described by Folch et al. (1957).

At the end of the feeding trial, three randomly selected fish per tank were euthanized with a lethal concentration of MS222 (100 mg/L) before collecting blood for health assays. Blood samples were drawn from anesthetized fish by puncturing the caudal peduncle with a heparinized needle. These were used to determine hematocrit (Hk) (collected with heparinized microhematocrit capillary tubes and centrifugation 3500 X g for 10 min), and hemoglobin (Hb) following Houston (1990). Mean corpuscular hemoglobin content (MCHC) was calculated according to the formula: MCHC = Hb (g/dL)/Hk. Serum obtained from the blood was used to analyze lysozyme activity using the procedures of Hutchinson and Manning (1996) with modification from Magnadottir (2006). The fish were then dissected, and the livers of the fish were weighed to calculate the hepatosomatic index (HSI = liver weight × 100/body weight).

The responses measured in the growth trial were analyzed by mixed model factorial analysis of variance (ANOVA) using PROC MIXED in SAS version 9.4 (SAS Institute Inc., Cary, N.C.). Data in percent form, proximate composition, and hematocrit, were arc-sin transformed before analysis. Lipid source and prebiotic served as the two independent fixed effects. When differences among treatment means were significant ($\alpha \leq 0.05$), Tukey's posthoc test was used to compare response differences among diets.

Results and Discussion

Percent weight gain was highest in fish fed the diet with the fish meal (Table 2). The fish fed the diets with regular soybean meal and PepSoyGen™ diets had similar percent weight gain. The addition of prebiotic did not alter percent weight gain. The feed conversion ratio (FCR) was better (lower) in the fish fed the fish meal diets.

This is commonly observed in Largemouth Bass and other fish species because the fish meal is palatable and highly digestible (Sampaio-Oliveira and Cyprino, 2008). There was an apparent palatability issue as well with the regular soybean and PepSoyGen™ diets, as some of the fish were observed rejecting the diets. This might explain why we did not see an increase in growth with the addition of prebiotic that has been observed in other studies (Yu et al., 2019). Survival was lower than expected in fish fed the regular soybean and PepSoyGen™ diets. Diet was not an obvious cause since all diets were formulated to be equivalent nutritionally, and we used common ingredients we have used previously in many trials. Fish were health-checked and there were no apparent diseases or parasites. The decrease in survival may be related to handling stress. Sadoul et al. (2016) found that Rainbow trout (*Oncorhynchus mykiss*) fed plant-based diets exhibited cortisol increases and more stress-related behavior than those fed diets with fish meal. We attempted to minimize handling stress of all Largemouth Bass in this study. However, we did not measure cortisol and do not have a quantitative index of stress response for fish fed different diets. This would be an interesting addition to future studies of carnivorous fish species fed plant-based diets.

Hemoglobin, hematocrit, MCHC, and lysozyme activity were not different among fish fed different diets (Table 3). Fermented products and prebiotics can sometimes influence immune parameters (Yu et al., 2019; Burr et al., 2005). However, non-specific immune responses such as lysozyme activity are not always affected by probiotics or prebiotics (Balcázar et al., 2007; Li and Gatlin, 2004; Thompson, 2016). The hepatosomatic index was higher in Largemouth Bass fed the fish meal and regular soybean meal diets in this study compared to the fermented soy diet. Tidwell et al. (2005) found that Largemouth Bass fed diets with soybean meal or fish meal as the main protein source had similar HSI values. Differences in nutrient availability of the main protein sources could affect the accumulation of either glycogen or lipid in the liver. However, the intake of the soy diets in this study was also reduced compared to the fish meal diet. Analysis of the glycogen and lipid content of livers would facilitate the interpretation of the HSI results. Prebiotics did not affect HSI in this study. Increased HSI of fish fed prebiotics or probiotics has been observed in some studies, but not in others (Keri et al., 2014; Munir et al., 2016). Differences in diet composition and experimental conditions across studies of different species make comparisons tenuous.

Practical Applications

The goal of increasing the inclusion of soybean meal in the diets of Largemouth Bass is to decrease diet cost and shift diet production toward more environmentally sustainable plant-based diets. Although the limitations of using soybean products and the prebiotic were evident in this study, the results laid the groundwork for further research using prebiotics and probiotics in conjunction with soybean meal to create more efficient products. The inclusion of palatants in soy diets could increase the potential of the treatments to enhance growth performance, and palatants will be evaluated in future trials. Information on the dynamics of gut microflora in response to soy products alone and combination with various feed additives also might inform future studies.

Acknowledgments

Partial support for this study was provided by Arkansas soybean producers through checkoff funds administered by the Arkansas Soybean Promotion Board. Tyson Foods of Springdale, Arkansas, donated the poultry by-product meal and poultry fat. Nutraferma of North Sioux City, S.D. donated the PepSoyGen™ for this trial. Cargill Inc., USA, donated the regular soybean meal. GroBiotic-A® was donated by International Feed Ingredient Corp., St. Louis, Mo. The assistance of UAPB graduate students - Katie McCann and Nathan Egnew - is greatly appreciated.

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Table 1. Composition of diets for feeding trial with largemouth bass fed different soy meals with or without prebiotics.

Ingredient (%)	Fish meal	Soybean meal	PepSoyGen™	Fish meal and Prebiotic	Soybean meal and Prebiotic	PepSoyGen™ and Prebiotic
Menhaden fish meal[a]	15.00	0.00	0.00	15.00	0.00	0.00
Poultry by-product meal[b]	25.00	32.00	25.00	25.00	32.00	25.00
Blood meal	2.00	4.00	4.00	2.00	4.00	4.00
Soybean meal[c]	28.00	35.00	20.00	28.00	35.00	20.00
PepSoyGen™[d]	0.00	0.00	24.00	0.00	0.00	24.00
Wheat flour	9.50	9.00	6.00	9.50	9.00	6.00
Corn starch	10.50	10.00	11.00	8.50	8.00	9.00
Menhaden fish oil	6.00	6.00	6.00	6.00	6.00	6.00
Poultry fat	2.00	2.00	2.00	2.00	2.00	2.00
Vitamin mix[e]	0.95	0.95	0.95	0.95	0.95	0.95
Stay-C	0.05	0.05	0.05	0.05	0.05	0.05
Mineral premix[f]	1.00	1.00	1.00	1.00	1.00	1.00
Prebiotic[g]	0.00	0.00	0.00	2.00	2.00	2.00
Analysis (%)						
Dry Matter	91.14	91.38	88.48	90.38	89.34	88.19
Ash	9.86	7.77	7.70	10.06	8.03	8.01
Fiber	2.35	6.05	6.78	3.16	3.06	6.91
Lipid	22.22	21.27	21.90	24.02	21.83	22.63
Protein	46.07	46.73	46.64	46.17	46.63	46.66

[a]Menhaden fish meal provided by Omega Protein (Houston, Texas), Special Select™.
[b]Poultry by-product meal provided by Tyson Foods (Springdale, Arkansas.), pet-fod grade.
[c]Soybean meal is dehulled, solvent-extracted 48% protein meal provided by Cargill, Inc. (Minneapolis, Minnesota).
[d]PepSoyGen™ provided by Nutraferma (North Sioux City, South Dakota), fermented with *Aspergillus oryzae* and *Bacillus subtilis.*
[e]Vitamin mix contains (% of premix) 5.0 ascorbic acid, 0.05 D-calcium pantothenate, 10.0 choline chloride, 0.5 inositol, 0.2 menadione, 0.5 niacin, 0.1 pyridixine•HCl, 0.3 riboflavin, 0.05 thiamine•HCl, 0.8 DL-α-tocopheryl acetate (250 international units (IU)/g), 0.5 vitamin A acetate (20,000 IU/g), 1.0 vitamin micro-mix, 80.55 cellulose. Vitamin micro-mix contains (% of micro-mix) 0.5 biotin, 0.02 cholecalciferol (D_3-40IU/µg), 1.8 folic acid, 0.02 vitamin B_{12}, 97.66 cellulose.
[f]Mineral mix contains (% of premix) 13.6.calcium phosphate monobasic, 34.85 calcium lactate, 0.5 ferrous sulfate, 13.2 magnesium sulfate, 24.0 potassium phosphate dibasic, 8.8 sodium phosphate monobasic, 4.5 sodium chloride, 0.015 aluminum chloride, 0.015 potassium iodide, 0.05 cupric sulfate, 0.07 manganous sulfate, 0.1 cobalt chloride, 0.3 zinc sulfate, 0.0011 sodium selenite.
[g]Prebiotic was GroBiotic-A®, donated by International Feed Ingredient Corp. (St. Louis, Mo.).

Table 2. Percent weight gain, feed conversion ratio (FCR), and survival of Largemouth Bass fed different diets.

Dietary treatments		Response variable		
Product	**Prebiotic**	**Percent Weight Gain**	**FCR[a]**	**Survival**
		%		%
Fish Meal	Basal	464.65	1.09	94.44
	Prebiotic	481.02	1.08	92.22
Soybean	Basal	234.95	1.85	63.33
	Prebiotic	175.73	2.18	52.22
PepSoyGen™	Basal	112.87	2.31	60.00
	Prebiotic	299.85	1.33	85.56
	Pooled SE	0.01	2.26	0.07
Main effect means[b]				
Fish Meal		472.83a	1.08b	93.33a
Soybean		205.34b	2.01a	57.78b
PepSoyGen™		206.36b	1.82a	72.78b
	Basal	270.83	1.75	72.59
	Prebiotic	318.87	1.53	76.67
Analysis of variance source, *Pr>F*				
Product (Po)		0.001	<0.01	<0.01
Prebiotic (Pr)		0.16	0.33	0.49
Po x Pr		0.02	0.07	0.06

[a]Feed conversion ratio (FCR) = dry feed intake / wet weight gained.
[b]All values are means of N = 3 replicate tanks of fish per diet. Main effect means in the same column with different letters are different ($P \leq 0.05$).

Table 3. Hepatosomatic index (HIS), hematological parameters and lysozyme activity of Largemouth Bass fed different diets.

Dietary treatments		Response variable				
Product	**Prebiotic**	**HSI[a]**	**Hb[b]**	**Hematocrit**	**MCHC[c]**	**Lysozyme Activity**
		%	**%**	**%**	**%**	**units/oz**
Fish Meal	Basal	2.85	8.19	44.68	18.76	37.79
	Prebiotic	2.66	7.50	39.68	19.49	40.23
Soybean	Basal	3.01	7.80	44.09	18.29	36.77
	Prebiotic	3.05	8.21	44.34	18.54	38.34
PepSoyGen	Basal	1.80	7.60	37.59	20.28	36.60
	Prebiotic	2.20	7.55	44.35	17.02	32.79
	Pooled SE	2.63	2.26	21.72	0.58	0.51
Main effect means[d]						
Fish Meal		2.75a	7.85	42.18	19.12	39.01
Soybean		3.03a	8.00	44.21	18.41	31.16
PepSoyGen		2.00b	7.58	40.97	18.65	34.69
	Basal	2.55	7.86	42.12	19.11	37.05
	Prebiotic	2.64	7.75	42.79	18.35	32.86
Analysis of variance source, *Pr > F*						
Product (Po)		<0.01	0.46	0.74	0.90	0.37
Prebiotic (Pr)		0.60	0.69	0.85	0.56	0.35
Po x Pr		0.36	0.29	0.39	0.40	0.46

[a]Hepatosymatic index (HSI) = is calculated by the following formula: fish liver weight (oz)/ body weight (oz) x 100.
[b]Hemoglobin (Hb) count.
[c]Mean corpuscular hemoglobin content (MCHC) is calculated by the formula: MCHC = Hb concentration/hematocrit fraction.
[d]All values are means of N = 3 replicate tanks of fish per diet. Main effect means in the same column with different letters are different ($P \leq 0.05$).

APPENDIX

2019-2020 Soybean Research Proposals

Principal Investigator (PI)	Co-PI	Proposal Name	Year of Research	Funding Amount (US$)
T. Barber	T. Butts, J. Norsworthy, and N. Burgos	A team approach to weed management	3 of 3	205,093
B. Bluhm	K. Cartwright	Accelerated development of bioherbicides to control Palmer amaranth (pigweed)	2 of 3	35,407
M. Daniels		Arkansas Discovery Farms	1 of 3	18,025
S. Green	M. Conaster	Assessment of soybean varieties in Arkansas for sensitivity to chloride injury	2 of 3	30,060
T. Faske	V. Ford, B. Bluhm, and J. Rupe	Assessment of the importance of target spot on soybean in Arkansas	3 of 3	43,969
L. Purcell	L. Mozzoni	Breeding and selecting for early maturing soybean with drought and heat tolerance	3 of 3	73,052
L. Mozzoni		Breeding new and improved soybean cultivars with high yield and disease resistance	3 of 3	194,499
L. Mozzoni	L. Purcell and C. Henry	Breeding soybean under reduced irrigation conditions	1 of 3	45,437
T. Faske	V. Ford and T. Kirkpatrick	Comprehensive disease screening of soybean varieties in Arkansas	2 of 3	124,746
J. Rupe	A. Rojas, J. Norsworthy, and T. Roberts	Cover crops and the control of soybean diseases	3 of 3	57,623
V. Ford	B. Watkins	Crop enterprise budgets and production economic analysis for soybeans	3 of 3	10,156
N. Bateman	J. Rupe and R. Stark	Determining the impact of disease and stinkbug feeding on soybean quality	1 of 3	89,273
V. Ford		Determining the value of fungicide application on regional, field level, and within-field scales	3 of 3	23,000
J. Kelley	J. Ross	Developing profitable irrigated rotational cropping systems	1 of 3	16,000
T. Roberts	J. Kelley and J. Ross	Developing winter cover crop recommendations for a soybean-corn rotation	3 of 3	38,110
T. Faske	A. Rojas	Development of an effective program to manage fungicide-resistant diseases of soybean in Arkansas	1 of 3	48,761
J. Robinson	T. Faske and T. Kirkpatrick	Development of an on-line course-nematology and sampling	2 of 2	7,498
B. Thrash	G. Lorenz, N. Joshi, G. Studebaker, and N. Bateman	Development of integrated management strategies for insects in soybeans	1 of 3	69,995
T. Roberts	B. Watkins, J. Kelley, and J. Ross	Double-cropped soybeans vs. cover-cropped soybeans–which is more profitable?	3 of 3	51,500
R. Stark		Economic analysis of soybean production and marketing practices	1 of 3	7,002
K. Kovacs	Q. Huang and C. Henry	Economics of irrigation technologies and practices	3 of 3	19,051

Continued

2019-2020 Soybean Research Proposals, continued.

Principal Investigator (PI)	Co-PI	Proposal Name	Year of Research	Funding Amount (US$)
G. Lorenz	B. Thrash and N. Bateman	Educating growers and consultants on insect monitoring and control	2 of 3	5,000
T. Roberts	N. Slaton and J. Ross	Fertilization of soybean and variety chloride trait classification	1 of 3	63,807
C. Willett	M. Reba, D. Leslie, and E. Grantz	Growing and non-growing season impacts of herbicides in recovered tailwater	3 of 3	75,009
J. Ross		Improving technology transfer for profitable and sustainable soybean production	3 of 3	30,900
R. Lochmann		Increasing nutrient utilization of soybean meals for largemouth bass through combined use of fermentation and prebiotics	1 of 1	18,800
T. Faske	T. Kirkpatrick, M. Emerson, and A. Greer	Integrated management of soybean nematodes in Arkansas	3 of 3	66,950
J. Ross	G. Lorenz	Investigating emerging production recommendations for sustainable soybean production	3 of 3	180,973
C. Willett	N. Burgos, M. Bertucci, and E. Grantz	Investigation of metolachlor resistance in Palmer amaranth in Arkansas	2 of 3	69,154
M. Bertucci	A. McWhirt and T. Roberts	Management and termination of cereal rye cover crops in Arkansas edamame production	1 of 2	18,755
A. Durand-Morat	L. Mozzoni	Preference assessment of soybean traits for its application in a public breeding program	1 of 1	23,358
C. Henry	P. Francis, L. Espinoza, and T. Spurlock	Promoting irrigation water management for soybeans	3 of 3	151,410
L. Mozzoni	G. Bathke	Purification and production of pre-foundation seed of UA soybean lines	3 of 3	47,190
J. Norsworthy	J. Ross	Screening for soybean tolerance to metribuzin	3 of 3	14,818
G. Phillips		Soybean Androgenesis by Isolated Microspore Culture	2 of 2	22,132
L. Mozzoni		Soybean Germplasm Enhancement Using Genetic Diversity	3 of 3	155,060
J. Ross	C. Norton and C. Elkins	Soybean Research Verification Program	3 of 3	177,574
J. Robinson	K. Ballard	Soybean Science Challenge	1 of 3	73,340
M. Reba	T. Teague, J. Massey, and N. Benson	Technology integration to improve irrigation efficiency in Arkansas soybean production	3 of 3	45,300
V. Ford	J. Rupe	Understanding charcoal rot and taproot decline; potential yield limiting soybean diseases in Arkansas	3 of 3	53,000
L. Mozzoni		Utilization of Chile for winter-nursery progeny rows to supplement MG4 soybean variety development	1 of 3	30,900
K. Korth	L. Mozzoni and N. Slaton	Utilizing chloride-tolerance markers and phenotypes to develop improved varieties	2 of 3	49,908
L. Purcell	J. Ross and M. Popp	Yield response of early- and late-planted soybean to N fertilizer and inoculant	3 of 3	43,973
			Total:	**2,625,568.00**

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